Northwest RiverPartners
For salmon, our economy and quality of life

December 7, 2018

VIA EMAIL

Becca Conklin
Washington State Department of Ecology
PO Box 47600
Olympia, WA 98504-7600

Re: Comments on Scope of EIS For Short-Term Modification of TDG Levels in the Columbia and Snake Rivers

Dear Ms. Conklin:

These comments are submitted on behalf of Northwest RiverPartners ("RiverPartners") in response to the Department of Ecology's ("Ecology") request for scoping comments on a draft Environmental Impact Statement ("EIS"). RiverPartners is an alliance between farmers, utilities, ports and businesses throughout the Columbia River Basin that represents more than 4 million electric utility customers, 40,000 farmers, thousands of port employees, and large and small businesses that provide hundreds of thousands of Northwest jobs.

Ecology is acting expeditiously in response to a request from the Columbia River Inter-Tribal Fish Commission, the Washington Department of Fish and Wildlife, and "non-governmental" groups including plaintiffs in the National Wildlife Federation v. NMFS, Case No., 3:01-cv-00640-SI (D. Or.), seeking to further relax the state's TDG water quality criteria. The purpose of the requested standards modification is to allow increased levels of spill that could produce up to 125% TDG at the tailrace of Lower Snake River and Lower Columbia River federal dams. For reasons outlined in this document below, RiverPartners has serious concerns about the waiver process and the merits of the requested modification and reiterates its request that there be a robust, transparent public process with comprehensive scientific review of the environmental impacts of the proposed waiver. RiverPartners further requests that Ecology extend the public comment period for an additional month to ensure adequate opportunity for stakeholders to submit meaningful comment.

Views on the "Flexible Spill" Proposal

RiverPartners is encouraged by the conceptual proposal animating the proposed standards modification. As we understand it, the proposal is to reduce spill during time periods when carbon-free hydropower is most valuable while also increasing spill during non-peak power generation hours. Given the adverse impacts of the ongoing Federal Columbia River Power System ("FCRPS") litigation, we appreciate the recent collaborative efforts of the states, Tribes and federal action agencies to get out of the courtroom and rally around an operational solution that is good for both the multi-users of the FCRPS and salmon. We appreciate the parties' recognition that it is in everyone's interest to develop a path that will keep BPA competitive so that the agency can continue to meet its statutory obligations to provide reliable, affordable and carbon-free energy to its customers, while funding fish and wildlife programs. We are concerned however that the "devil is in the details" because there is not yet enough information provided in Ecology's scoping document to determine exactly what is being proposed.

It is our understanding that this modified spill operation is due to begin in April of 2019 and continue until the spring spill period ends in June, and that such operations will continue annually for a period of three years. We understand that this proposal is guided by three principles. First, this operation must provide benefits for BPA that will help to preserve the agency's financial health and competitiveness. Second, the proposal will provide benefits for salmon and steelhead survival. And third, this proposed operation will eliminate the need for further litigation of the FCRPS Biological Opinion for the same period. As described more fully below, issues raised by this proposal have been the subject of contentious litigation pending in the District of Oregon Federal Court in *National Wildlife Federation v. NMFS*, Case No 3:01-cv-00640-SI (D. Or), and do not lend themselves to an "easy fix." Along these lines, we have outlined specific procedural and legal concerns below.

Procedural and Legal Concerns

<u>The comment period is too short for adequate evaluation</u> - The time period that Ecology has provided the public for the scoping process is inadequate. As you know, the level and timing of spill required at the federal dams in the Lower Snake and Columbia Rivers has been a very contentious issue in pending litigation challenging the FCRPS BiOp. RiverPartners has been deeply involved in these issues as a party to the federal litigation for the last 13 years. In addition, River Partners has been actively involved in water quality issues surrounding spill, including intervening **in support** of Ecology in past litigation to preserve Ecology's existing TDG WQS and associated "waivers."

According to the best available science from NOAA Fisheries, higher and higher levels of spill at all 8 dams does not significantly improve salmon survivals and is not justified as a blanket solution for all dams. RiverPartners does not support proposals that seek to increase spill, and thus TDG, at any economic and biological cost without a sound scientific basis. Modeling performed by NOAA of increased spill levels show little to no biological benefit from increased spill.

There is a lack of clarity surrounding the process - Ecology's proposed water quality waiver and scoping document consists of one step: analyzing flex spill operations up to 125% TDG beginning in 2019. RiverPartners has heard that the waiver process will occur in two steps: 1) continue federal hydrosystem operations to 120% TDG in 2019; and; 2) "test" flex spill operations up to 125% TDG in 2020 and 2021. We request that Ecology provide clarity about what operations are proposed to be covered by the wavier and when so that parties can effectively engage in the EIS process.

The relationship to USACE waiver process is unclear - The U.S. Army Corps of Engineers (USACE) water quality waivers for operating the federal hydropower system expire this month. The current TDG spill exemption includes a 115% forebay and a 120% tailrace requirement. Ecology's proposal would further increase the exemption to allow for even higher levels of TDG in the tailrace but are unclear about what levels, if any, will be required in the forebay. One component of the proposal would eliminate the forebay requirement, and another would eliminate both components to allow for as much as 125% saturation in the tailrace.

The proposed waiver does not meet the state's standards for a "short term" waiver - Ecology describes the TDG proposal as a "short-term" modification of WAC 173-201A-200(1) (f) (ii), and defines "short-term" to include up to three full years. Ecology appears to be relying on a regulation found at WAC 173-201A-410 entitled ("short-term modifications") as the legal authority for the water quality standard modification itself. But that provision defines "short term" as "hours or days rather than weeks, months or years." *Id*. While we understand that the proposal would allow a variation from the TDG standard for 16 hours each day, the proposed "flex spill" would occur each and every day for 16 hours during the spring months of April, May and part of June. The proposed "short term" increased spill level is then proposed to repeat over a period of three years. That lengthy duration is clearly not what is intended by the plain language of "short term modification" regulation established under WAC 173-201A-410. Accordingly, Ecology's legal authority for the proposed modification appears to be seriously lacking, and RiverPartners is very concerned with the potential precedent this may set for any future proceedings.

Monitoring and metrics - Ecology's scoping document needs to describe how the proposed operations and spill "test" will be monitored and what metrics will be used. A rigorous monitoring program is absolutely essential to gather adequate data to determine whether the waiver is being complied with, and whether migratory salmon and other biological communities are being protected – or harmed. Otherwise, the entire purpose of implementing a waiver to conduct "test" spill operations is undermined. Ecology also needs to make clear what metrics will be used to measure impacts of higher spill levels. Our understanding is that Ecology intends to use the Fish Passage Center's CSS modeling as the basis for the waiver and smolt-to-adult returns (SARs) as a key metric. As described more fully below, RiverPartners has serious concerns with the use of SARs.

Specific Issues or Analysis That Should Be Addressed in the EIS:

- Ecology should identify the biological basis for removing the compliance requirement provided by the forebay monitors. The scoping document states: "Modifying the TDG criteria as described may also facilitate alignment of TDG criteria with Oregon. By doing so, it could simplify implementation of the spill program by the U.S. Army Corps of Engineers." RiverPartners' understanding is the opposite: the USACE relies on Washington's forebay monitors to help control spill levels and impacts on fish as they pass each project. RiverPartners questions why the agency would want to monitor less of a known pollutant that can adversely affect salmon and other aquatic species.

- The impacts of increased spill on carbon emissions and climate change need to be analyzed. Washington's stated policy is to significantly reduce carbon emissions. The Northwest Power and Conservation Council ("Council") conducted an analysis of the impacts of removing the four Lower Snake River dams, "Carbon Dioxide Footprint of the Northwest Power System", Council Document 2007-15 (attached as Ex. A). The Council, modeled a scenario assuming that the Lower Snake dams would be removed, found that carbon dioxide emissions in the western power grid would increase by 4.4 million tons per year. In this study the Council also estimated the impacts of the summer spill program that was under court order at that time. The Council found that the summer spill program increased carbon dioxide production in the west by 2.4 million tons in comparison to a situation where the dams operate *without* summer spill.

- The EIS should include analysis of the impacts of increased TDG on the entire river ecosystem including other critical species such as lamprey, sturgeon, and the entire aquatic food web that salmon depend on.

- As previously noted, the waiver proposal states: "it relies on and will test" the FPC's CSS analysis to gauge anticipated fish benefits. The FPC's proposal to increase spill levels to 125% TDG was submitted to the Independent Science Advisory Board (ISAB) in 2014 for review (attached as Ex. B). The ISAB pointed out the proposal could result in higher juvenile mortality – not less. RiverPartners' understanding is that the FPC has not corrected flaws identified by the ISAB in its analysis, yet Ecology proposes to use it as the basis for the waiver.

Given the ISAB concerns, Ecology also should also evaluate changes in smolt survivals based on NOAA modeling of the entire lifecycle using the COMPASS model. NOAA is the relevant agency responsible for issuing Recovery Plans and Biological Opinions for the ESA listed salmon and Steelhead in the Columbia and Snake Rivers. Their analysis and modeling should be given great weight in the EIS process.

- The use of SARs to measure the effects of spill is flawed. The federal hydrosystem continues to be held wholly accountable for meeting SAR’s goals. SARs are affected by far more than the hydrosystem including ocean conditions, predation, habitat, harvest, and hatchery impacts, among other factors. It is well recognized amongst the scientific community that the overwhelming factor affecting adult returns is ocean conditions. We have serious technical concerns with measuring survival benefits from changes in spill with the lifecycle metric of SARs.

- The EIS should review actual reported reach survivals from Lower Granite to Bonneville over the last 20+ years to determine changes in fish survivals during periods of high and low spill. NOAA produces an annual report reporting reach survivals for juvenile salmon and steelhead every year. The latest report (attached as Ex. C) shows that for both 2017 and 2018 juvenile survivals were lower in the last two years than the 10 average except for Snake River steelhead which increased survival in 2018, for no apparent reason. However, spill levels in both years were above the levels ordered by the Court due to unusually high flows that exceeded power generation capability for much of the spring period.

- Evaluate the impacts on adult passage and survival of high levels of spill at each dam.

- Evaluate the impacts of high continuous spill levels on dam safety.

- Evaluate impacts on power and revenue loss and how it will impact BPA's economic viability. This should include analysis of the potential rate impacts on Northwest ratepayers, especially the disadvantaged groups such as low income and tribal members.

In summary, given serious scientific uncertainties, a long history of litigation, and the grave risks posed by ever increasing levels of accumulated TDG on adult and juvenile salmon the scope of the proposed EIS needs to be comprehensive and the analysis needs to be very detailed to properly inform Ecology’s decisions. RiverPartners reiterates that it *does* support the goals articulated in Ecology’s waiver of improving salmon survivals while keeping BPA’s costs contained. However, Ecology's current scoping document is short on critical details necessary to understand and gauge the prospects for a comprehensive EIS to guide future regulatory decisions.

Thank you for the opportunity to comment. RiverPartners' interest is to ensure Ecology procedurally, publicly and scientifically approaches the proposed EIS in a way that recognizes and protects endangered fish and other aquatic species while preserving the critical climate change, renewable energy and other multiple, critical benefits afforded by the federal hydropower and Columbia and Snake river systems.

Very truly yours,

Terry Flores

Terry Flores
RiverPartners Executive Director

EXHIBIT A

CARBON DIOXIDE FOOTPRINT
OF THE
NORTHWEST POWER SYSTEM

November 2007

Northwest Power and Conservation Council

Council Document 2007-15

This report summarizes the results of an analysis of CO2 production from the Pacific Northwest power system. It compares 2005 CO2 production to levels in 1990 and to forecast future levels. The analysis explores how future growth in CO2 production would be affected by various resource development scenarios and other policies of interest.

Summary of Findings

Following a 2006 staff analysis of the marginal carbon dioxide (CO2) effects of conservation called for in the Council's Fifth Power Plan, the Council requested additional analysis of the CO2 production of the Northwest power system under various future resource development scenarios. The scenarios included the recommended resource portfolio of the Fifth Power Plan (the base case), a low-conservation scenario in which the conservation targets of the Fifth Power Plan are not achieved, and a high-renewables scenario based on state renewable energy portfolio standards. A scenario based on the resource acquisition recommendations of utilities' integrated resource plans (IRPs) was dropped following the release of several revised utility IRPs that closely matched the recommendations of the Fifth Power Plan. In addition, the Council asked for sensitivity analysis of several specific policies related to hydro system operations to understand how related scenarios could affect the CO2 production of the power system. The analysis does not address CO2 production from other sources such as transportation or industrial processes.

The actual CO2 production of the Northwest power system in 1990 is estimated to have been about 44 million tons.[1] By 2005, production of CO2 from the regional power system rose to an estimated 67 million tons. However, 2005, unlike 1990, was a poor water year, requiring more than normal operation of CO2 -producing fossil power generation. Under normal water conditions, the CO2 production in 2005 would have been about 57 million tons, which is a 29 percent increase over the 1990 level. For perspective, the annual CO2 output of a typical 400-megawatt coal-fired power plant is about 3 million tons, and the CO2 output of a typical 400-megawatt gas-fired combined-cycle power plant is about 1.2 million tons.[2]

Factors contributing to the increase from 1990 to 2005 include economic growth, the addition of fossil-fueled generating units, lost hydropower production capability, and retirement of the Trojan nuclear plant. The year 1990 is used for comparison because 1990 has been adopted as a baseline by many climate-change policy proposals, including Washington Governor Gregoire's climate-change executive order, Oregon HB 3543, and national legislation proposed by Senators Lieberman and Warner.

Due to the large share of hydroelectric generation in the Pacific Northwest, CO2 production here is much less than that of other regions when compared to electricity produced. For example, under normal water conditions, in 2005 the Pacific Northwest would have produced about 520 pounds of CO2 for each megawatt-hour of electricity generated, compared to 900 pounds for the entire Western interconnected power system (WECC). However, because the Northwest has essentially the same set of future resource options available as other areas of WECC, it may be more difficult for the Northwest to maintain or reduce its average per-megawatt-hour CO2 emission rate. In the base case of this study, which assumes implementation of the Council's Fifth Power Plan, the WECC CO2 emission rate increases about 3 percent to about 920 pounds per megawatt-hour by 2024, whereas the Northwest rate, with aggressive development of conservation and renewables also increases 3 percent to about 530 pounds.

The future growth rate of annual regional CO2 production would be even higher if the conservation, wind, and other resource development called for in the Council's Fifth Power Plan were not accomplished. With implementation of the Council's plan in the base case, the annual CO2 production of the regional power system in 2024 under normal conditions would be about 67 million tons, an 18 percent increase over normal 2005 levels.

This paper explores the difficulty of reducing CO2 production from electricity generation by assessing the effects of several scenarios on CO2 production. The scenarios include some that would increase CO2 production and some that would decrease it. These

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[1] Unless otherwise noted, quantities are expressed as short tons (2,000 pounds) of carbon dioxide.

[2] A 400-megawatt pulverized coal-fired plant of 10,000 Btu/kWh heat rate operating at 80 percent capacity factor will produce about 3 million tons per year of carbon dioxide. A 400-megawatt combined-cycle plant fueled by natural gas of 7,000 Btu/kWh heat rate operating at 80 percent capacity will produce about 1.2 million tons per year of carbon dioxide.

scenarios were selected to develop a “scale-of-effects” sensitivity analysis that includes alternative resource development scenarios and hypothetical changes to the hydroelectric system. The hydroelectric sensitivity analyses address two hypothetical river condition alternatives: “no summer spill” and breaching the four lower Snake River dams. The controversial nature of these two scenarios is recognized, but has no relevance in this paper other than the CO2-related data the alternatives generate as a result of their respective scenario parameters.

An important finding of the analysis is that achieving the renewable portfolio standard goals and eliminating all summer spill would reduce the region’s projected growth in power system CO2 production by only 75 percent, even if counting the resulting net CO2 reduction for the entire WECC. Failure to achieve the conservation targets in the Fifth Power Plan, or removing the lower Snake River dams and replacing the power in a manner consistent with the Fifth Power Plan could more than offset the potential savings from the scenarios that reduce CO2 production. The effects of these scenarios, positive or negative, on CO2 production are the equivalent of only one or two coal-fired plants, whereas the forecast regional CO2 production for 2024 in the Fifth Power Plan case exceeds 1990 levels by an amount equivalent to eight typical coal-fired plants.

The findings of this study are depicted in Figure 1 and compiled in Table 1. Figure 1 depicts changes from base case projected CO2 emissions from WECC power systems for each of the scenarios. Table 1 shows the CO2 emissions in 1990, 2005, and projections for 2024 in each scenario, both for the Pacific Northwest and the WECC as a whole. Changes to the 2024 levels are shown in parentheses for each scenario.

These results illustrate the difficulty of actually reducing CO2 production with policies that affect only new sources of electric generation. CO2 production from electricity generation is dominated by existing coal-fired generating plants. To stabilize CO2 production at 2005 levels or to reduce CO2 production to 1990 levels would require substituting low CO2-producing resources or additional conservation for some of these existing coal-fired power plants. In addition, the scenario analysis shows that policy choices that are made for purposes other than CO2 reduction (in this case fish and wildlife policy) can also have significant effects on CO2 production; enough effect to negate policies such as renewable portfolio standards. Such unintended effects often go unexplored in important policy debates that focus narrowly on only one objective.

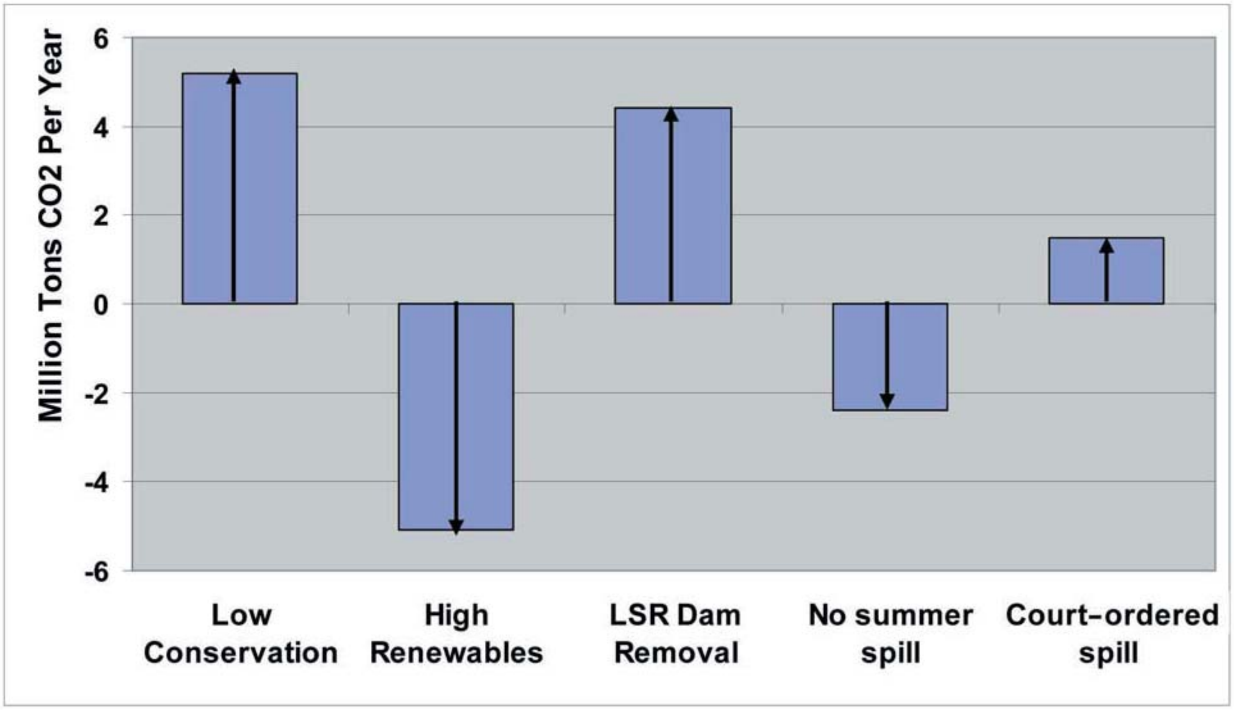

Figure 1: Changes from the base case projected CO2 production in alternative scenarios (WECC)

	Northwest Sources	WECC Sources
Historical values		
Actual 1990	44	Not estimated
Actual 2005	67	Not estimated
Simulated 2005 w/average hydro	57	378
Forecast 2024 rates and change from base case		
Base Case (5th Plan Portfolio)	67	531
Low Conservation	71 (+4.4)	536 (+5.2)
High Renewables	63 (-4.2)	526 (-5.1)
Remove LSR Projects, Replace w/Gas Generation	70 (+3.6)	536 (+4.4)
No Summer Spill	66 (-1.1)	529 (-2.4)
Court-ordered Spill	67 (+0.5)	533 (+1.5)

Table 1: Historical and projected CO_2 production and effects of alternative scenarios

As perspective, it is useful to understand regional CO2 emissions in a global context. In 2005, the world production of CO2 from the consumption and flaring of fossil fuels is estimated to have been about 28,000 million metric tons (30.8 billon short tons). The United States accounted for 21 percent of these emissions. The U.S. production of CO2 per capita is about 5 times the world average, largely reflecting its advanced state of development. However, the U.S. production of CO2 relative to its state of development as measured by Gross Domestic Product is substantially lower than the world average; about 70 percent of the world average.[3]

Electric power generation accounts for about 40 percent of the U.S. production of CO2. The electric power share is much lower in the Western U.S., however, at about 31 percent, and even lower for the Pacific Northwest where the 2004 (a fairly normal water year) share was 23 percent.

Greenhouse gas reduction targets, such as the Western Climate Initiative, typically target all sources of greenhouse gas emissions. Carbon dioxide is the dominant greenhouse gas. It accounted for 84 percent of all greenhouse gas emissions in 2005.[4] Sources of CO2 emissions other than electricity generation will need to be reduced to meet greenhouse gas reduction targets. For the U.S. as a whole, electricity generation is the largest producer of CO2. It is followed closely by the transportation sector, which accounts for one-third of emissions, and then by the industrial sector contributing 18 percent. The residential and commercial sectors combine to account for 10 percent.

Although electricity generation is the largest source of CO2 emissions in the U.S., in the West transportation is the largest. Transportation accounts for 43 percent of the CO2 emission in the West compared to 33 percent in the U.S. as a whole. In the Pacific Northwest, the transportation share is even larger at 46 percent.

The diversity of CO2 emission shares should be an important consideration in structuring CO2 reduction policies. In the West, with a smaller contribution to CO2 emission coming from electricity production, other sectors will need to carry a larger burden in reaching overall CO2 reduction targets. In addition, as discussed later in this paper, the CO2 production for electricity generation in the Pacific Northwest can vary significantly with changing hydroelectric supplies. This variability will need to be accounted for in setting CO2 reduction targets and in any cap and trade allocation system.

Background

Increasing concerns regarding the impact of CO2 production from the electric power system on global climate and heightened prospects of mandatory

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[3] Data on CO2 emission from energy are from the U.S. Energy Information Administration.
[4] U.S. Environmental Protection Agency. EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005.

controls on the production of CO2, led the Council in the summer of 2006 to request a forecast of the CO2 produced from alternative future resource portfolios. Four scenarios were identified: the recommended resource portfolio of the Fifth Power Plan (the base case), a low-conservation scenario in which the conservation targets of the Fifth Power Plan are not achieved, a high-renewables scenario based on state renewable energy portfolio standards, and a scenario based on the resource acquisition recommendations of utilities' integrated resource plans (IRPs). The utility plans scenario was removed from the final paper following the release of several revised utility IRPs that closely matched the recommendations of the Fifth Power Plan. Two additional sets of studies were subsequently requested: 1) the CO2 effects of removing the federal dams on the lower Snake River; and 2) the CO2 effects of summer spill at the lower Snake River and lower Columbia River dams.

The purpose of these alternative scenarios is to quantify the sensitivity of results to plausible changes in the power system and to some related policies that have received attention. No new Council position on any of these policies is intended by this analysis, nor should any be inferred.

Historical Carbon Dioxide Production of the Northwest Power System

The year 1990 is frequently used as a benchmark in policies for the control of greenhouse gases.[5] The 1990 production of carbon dioxide from the Pacific Northwest power system is estimated to have been about 44 million tons, based on electricity production records of that year. Load growth, the addition of fossil-fuel generating units, the loss of hydropower production capability, and the retirement of the Trojan nuclear plant resulted in growing CO2 production over the next 15 years. By 2005, the most recent year for which electricity production or fuel consumption data are available, CO2 production increased 52 percent to 67 million tons (Figure 2). This is approximately the CO2 output of 23 400-megawatt conventional coal-fired power plants, 56 400-megawatt gas-fired combined-cycle plants or about 11.7 million average U.S. passenger vehicles.

The regional CO2 production estimates from 1995 through 2005 shown in Figure 2 are based on the fuel consumption of Northwest power plants as reported to the Energy Information Administration (EIA). Because fuel consumption data were not available before 1995, estimates for 1990 through 1995 are based on plant electrical output as reported to EIA and staff assumptions regarding plant heat rate and fuel type. Estimates based on plant electrical production are likely somewhat less accurate than estimates based on fuel consumption because of multi-fuel plants and uncertainties regarding plant heat rates. However, the two series of estimates are within 2 percent in the "overlap" year of 1995.

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[5] For example, California Assembly Bill (AB) 32, passed by the legislature and signed by the governor in 2006, calls for enforceable emission limits to achieve a reduction in CO2 emissions to the 1990 rate by 2020. Washington Governor Gregoire's climate-change executive order includes the same target for CO2 reductions. Oregon House Bill 3543, passed by the legislature and signed by Governor Kulongoski in August, declares that it is state policy to stabilize CO2 emissions by 2010, reduce them 10 percent below 1990 levels by 2020, and 75 percent below 1990 levels by 2050.

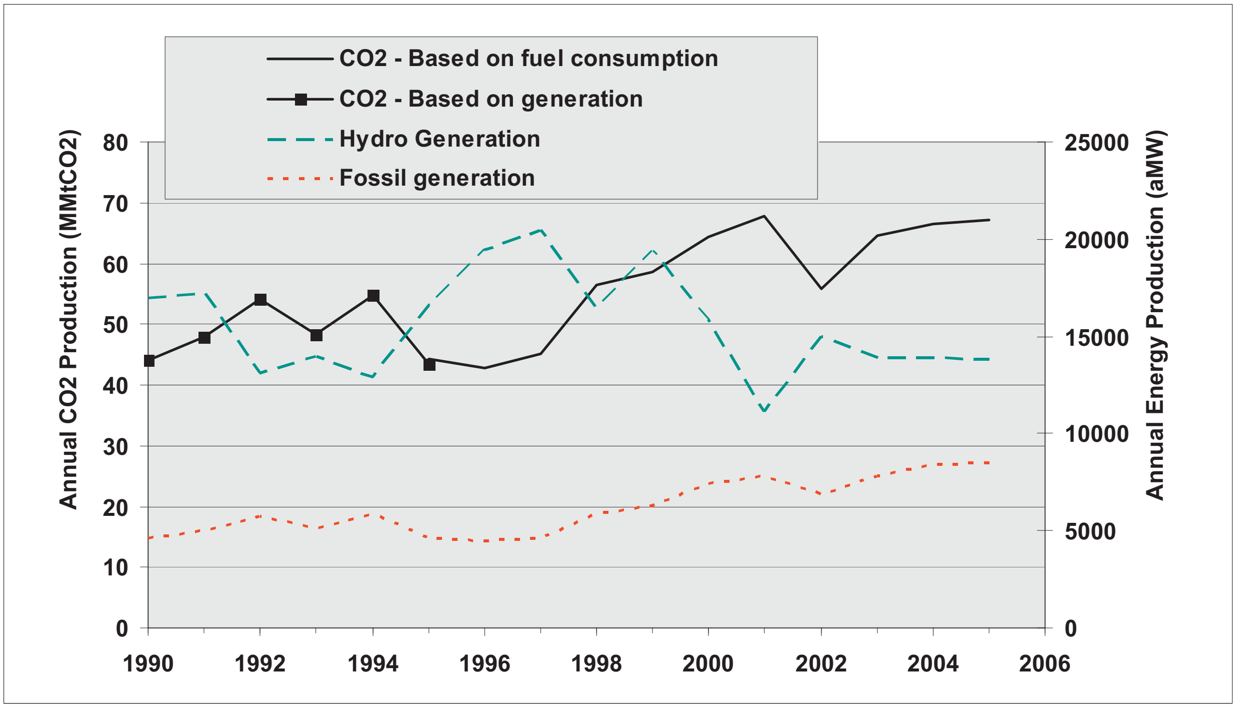

Figure 2: Historical CO2 and energy production of the Northwest power system[6]

Annual hydropower conditions can greatly affect power system CO2 production. Average hydropower production in the Northwest is about 16,400 average megawatts. As shown by the plot of Northwest hydropower production in Figure 2, the 1990 water year was nearly 17,000 average megawatts, slightly better than average. Other factors being equal, this would have slightly reduced CO2 production that year by curtailing thermal plant operation. Conversely, hydro production in 2005 was about 13,800 average megawatts, a poor water year. Other factors being equal, this would have increased thermal plant dispatch, raising CO2 production. The effect of hydropower generation on thermal plant generation and CO2 production is shown in Figure 2.[7]

If normalized to average hydropower conditions, actual generating capacity, and the medium case loads and fuel prices of the Fifth Power Plan, the estimated CO2 production in 2005 would have been 57 million tons, a 29 percent increase over the 1990 rate. This is the value used for comparison in this paper.

The Base Case - The Fifth Power Plan's Portfolio

The recommended resource portfolio of the Fifth Power Plan was used as the base case for all studies. Because the recommended resource portfolio of the Fifth Power Plan is defined in terms of "option by" dates rather than in-service dates, assumptions must be made to translate the portfolio into the fixed resource schedule needed for the AURORA™ model.[8] For this work, the "mean value resource development" schedule of the preferred resource portfolio of the Fifth Power Plan was represented in AURORA. The resulting resource development schedule was then tested against the Resource Adequacy Forum's recently proposed pilot capacity adequacy standard, using the capacity addition mode of the AURORA model. The resulting resource development schedule, illustrated in Figure 3 and enumer-

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[6] Estimated CO2 production from 1995 through 2005 is based on power plant fuel consumption as reported to the U.S. Energy Information Administration (EIA). Fuel consumption information before 1995 is not readily available. CO2 production for these years was based on reported generation and estimated plant heat rates. As evident in Figure 1, the two methods result in reasonably consistent estimates for the overlap year of 1995. Incomplete reporting of generation for the increasing amount of non-utility power plant capacity makes comparisons less reliable for subsequent years. Estimates are based on all utility-owned power plants and non-utility plants selling under contract to utilities. Included in the definition of "Northwest" are the Jim Bridger plant in Wyoming and the Idaho Power share of the North Valmy plant in Nevada. The output of this capacity is dedicated to Northwest loads.

[7] In Figure 1, it is evident that Northwest thermal generation does not decline as much as Northwest hydro generation increases in above average water years, e.g. 1994 - 1997. This is likely due to the fact that the abundant hydropower of good water years creates a regional energy surplus that can be sold out of the region where it displaces thermal generation, which often consists of older, less efficient gas-fired units.

[8] The use of the AURORA model in preparing these forecasts is described in the Appendix A of this paper.

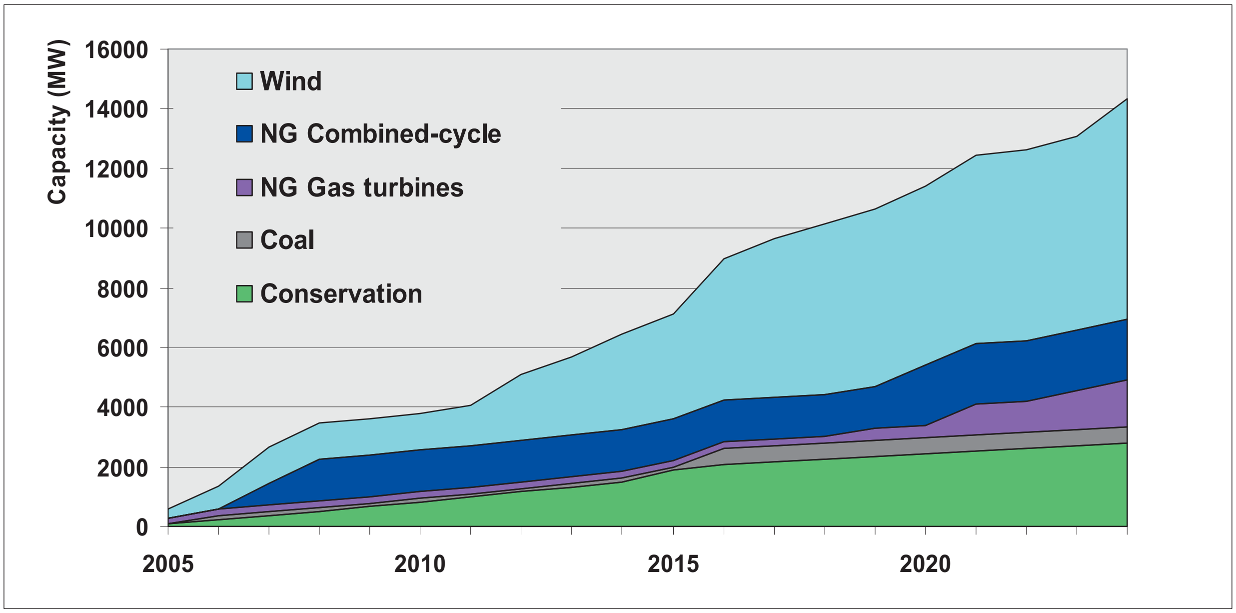

Figure 3: Base case Northwest resource development

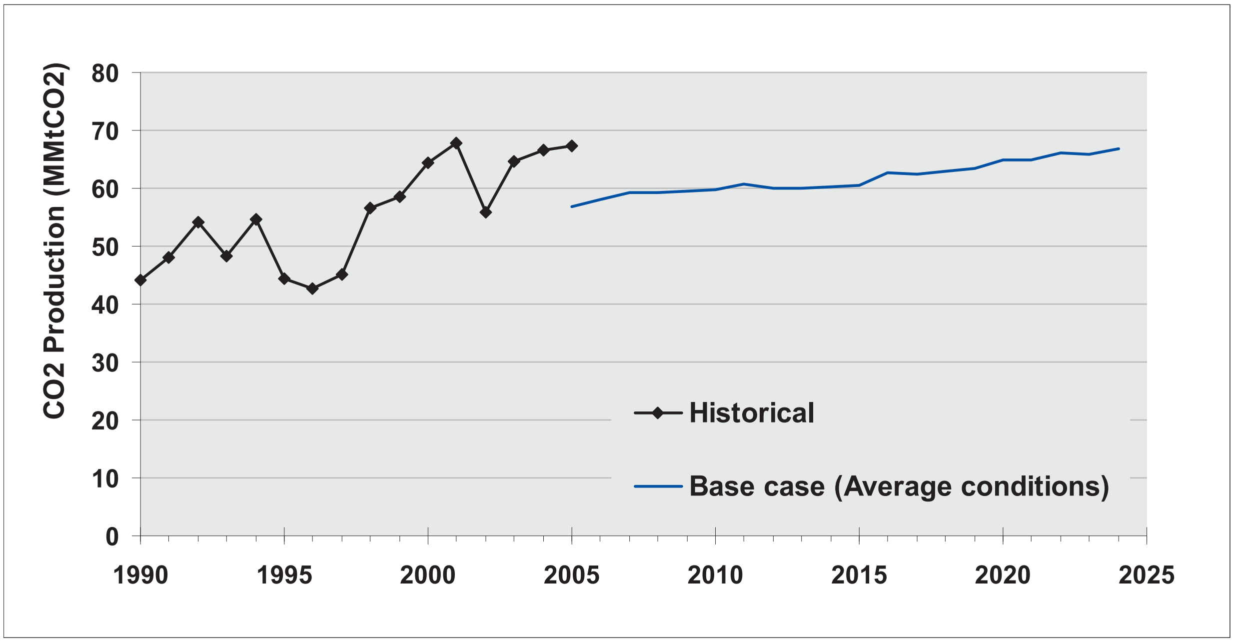

Figure 4: Forecast and historical CO2 production of the Northwest power system

ated in Appendix B, contains additional simple-cycle gas turbine capacity needed to maintain the proposed Northwest pilot capacity reserve standards. The schedule also contains several recently constructed wind projects not included in the resource portfolio of the Fifth Power Plan, so it includes a somewhat larger amount of wind capacity by 2024 than the original Fifth Plan portfolio. The AURORA capacity expansion run was also used to define resource additions and retirements for WECC areas outside the Northwest.

Forecast CO2 production of the Northwest power system for 2005-24 is compared to historical production in Figure 4. The forecast is normalized to average hydro, fuel prices, and loads, leading to the difference between actual and forecast values for the low water year 2005. Annual CO2 production under average conditions is forecast to increase from 57 million tons in 2005 to 67 million tons in 2024. This represents an 18 percent increase over the planning period of the Fifth Power Plan, an average annual rate increase of 0.8 percent. The forecast annual rate

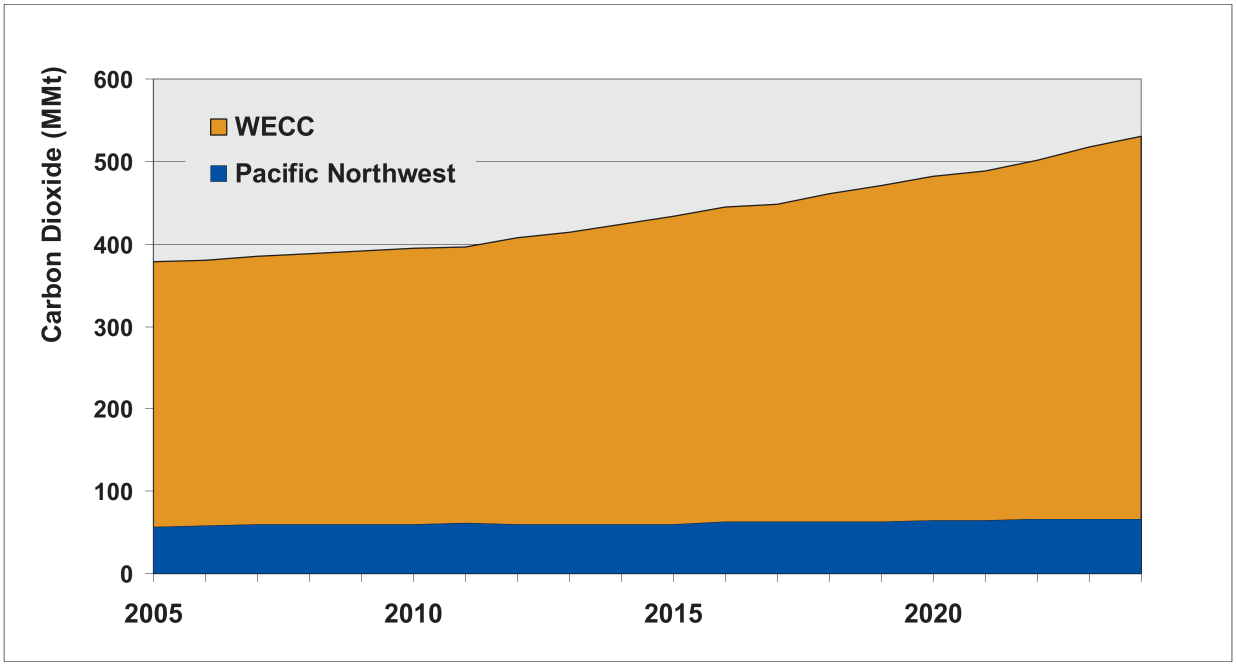

Figure 5: Forecast WECC and Northwest power system CO2 production

of 67 million tons in 2024 represents an increase of 51 percent over the historical annual rate of 44 million tons in 1990. The forecast average annual rate of increased CO2 production of 0.8 percent for the planning period of the Fifth Power Plan is half of the 2 percent average rate for 1990 - 2004 (2004 normalized).

Figure 5 compares forecast annual CO2 production for the Northwest and the WECC as a whole. In 2005, the normalized annual CO2 production by the Northwest power system represented 15 percent of the total WECC production. Because of its high proportion of hydropower, aggressive development of conservation, and recent additions of wind power and other non-hydro renewable resources, the Northwest enjoys a much lower per-kilowatt-hour CO2 production rate than WECC as a whole (0.52 lb/kWh vs. 0.90 lb/kWh in 2005). The forecast average annual growth rate for WECC as a whole is 1.7 percent, compared to 0.8 percent for the Northwest, so that by 2024, the production in the Northwest will have declined to 13 percent of the total WECC production. Because these estimates do not include the possible effects of the renewable portfolio standards in place in many Western states (including the Northwest states), the future growth of CO2 production for WECC may be less than forecast here.

Figure 6 illustrates the source of CO2 production in the Northwest in the base case forecast. By 2024, and assuming no retirements of existing thermal plants, 79 percent of Northwest power system CO2 production will be from existing coal-fired power plants, 4 percent from new coal-fired plants, 9 percent from existing gas-fired plants, and 7 percent from new gas-fired power plants. Though the aggressive acquisition of conservation and renewable resources called for in the Fifth Power Plan will hold the rate of growth in Northwest CO2 production to half the growth rate experienced from 1990 through 2004, serious efforts to reduce or even stabilize CO2 production beyond 2005 will likely require replacing existing coal-fired power plants with low CO2-emitting resources.

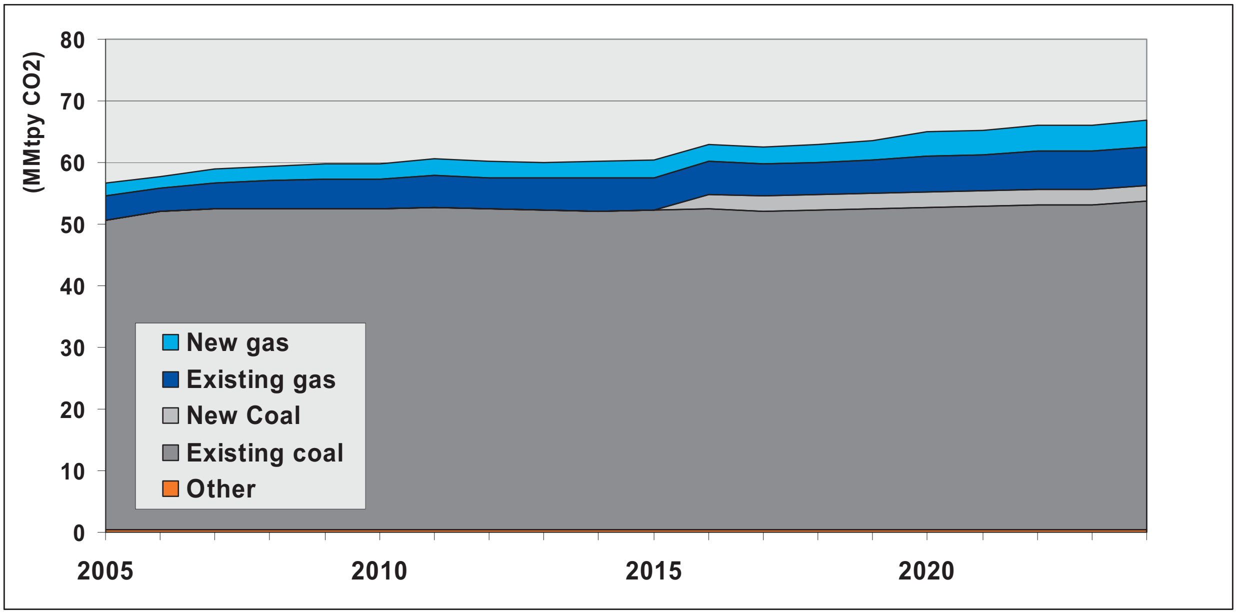

Figure 6: Sources of Northwest power system CO2 production

Alternative Resource Development

The CO2 production of two scenarios of alternative future resource development was forecast and compared to the base case forecast described earlier. The Northwest resource-development assumptions for each scenario are described below. Resource-development assumptions for WECC areas outside of the Northwest are the same as the base case. The impacts of all of the scenarios analyzed in this paper are assessed under average water conditions.

Alternative resource-development scenarios

A low-conservation scenario assumes that only 70 percent of the long-term conservation goals of the Fifth Power Plan are met by 2024. A resource portfolio (the "status quo" portfolio) representing this situation, developed during preparation of the Fifth Power Plan, was adopted for this scenario. As shown in Figure 7, this portfolio includes 800 fewer megawatts of conservation, 200 fewer megawatts of wind, and 275 fewer megawatts of simple-cycle capacity compared to the base case.[9] An additional 275 megawatts of coal and 610 megawatts of combined-cycle capacity make up for the energy and capacity of the unachieved conservation, wind, and gas turbine capacity.

A high-renewables scenario approximates full achievement of the Montana, Oregon, and Washington renewable portfolio standards (RPS). This scenario also includes a hypothetical RPS for Idaho, generally comparable to those adopted by the other states but with a lag of several years. Although these additional renewable resources were not found to be cost-effective in the Council's Fifth Power Plan, their acquisition has been mandated by many states, including Montana, Washington, and Oregon. Renewable-resource acquisitions to meet RPS goals are modeled as a combination of wind and biomass in the approximate proportions of wind currently being developed compared to other renewable energy resources. Though some geothermal, hydropower, solar, and marine energy resources are expected to be developed in response to renewable portfolio standards, the wind and biomass assumed for this scenario adequately represent the performance of the expected mix of intermittent and firm renewable energy resources for this purpose. The conservation-acquisition targets of the Fifth Power Plan were also assumed to be met. New coal-fired generation is excluded from this scenario. As shown in Figure 7, the high-renewables scenario includes an additional 500 megawatts of biomass, 1,600 megawatts of wind,

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[9] In Figure 7 and following figures, column sections above the zero line represent resource capacity in excess of the amounts included in the base case, and column sections below the zero line represent resource capacity less than included in the base case. Conservation energy savings are shown as equivalent capacity.

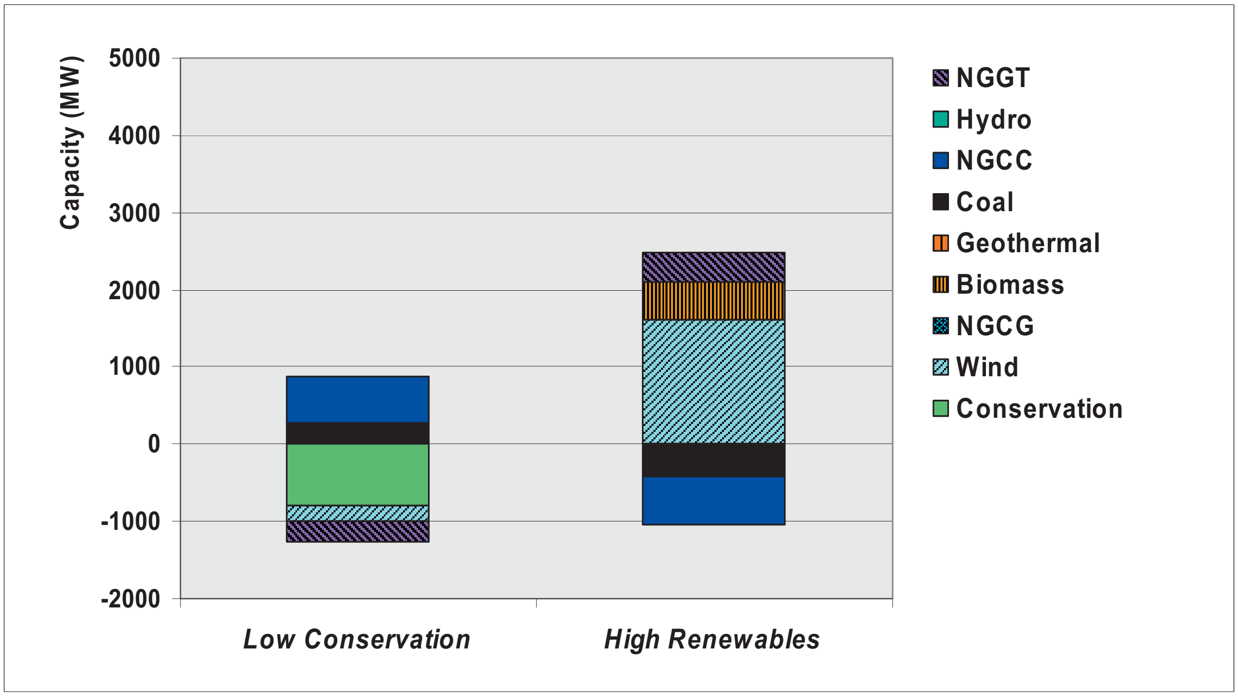

Figure 7: Incremental 2005-24 capacity compared to the base case

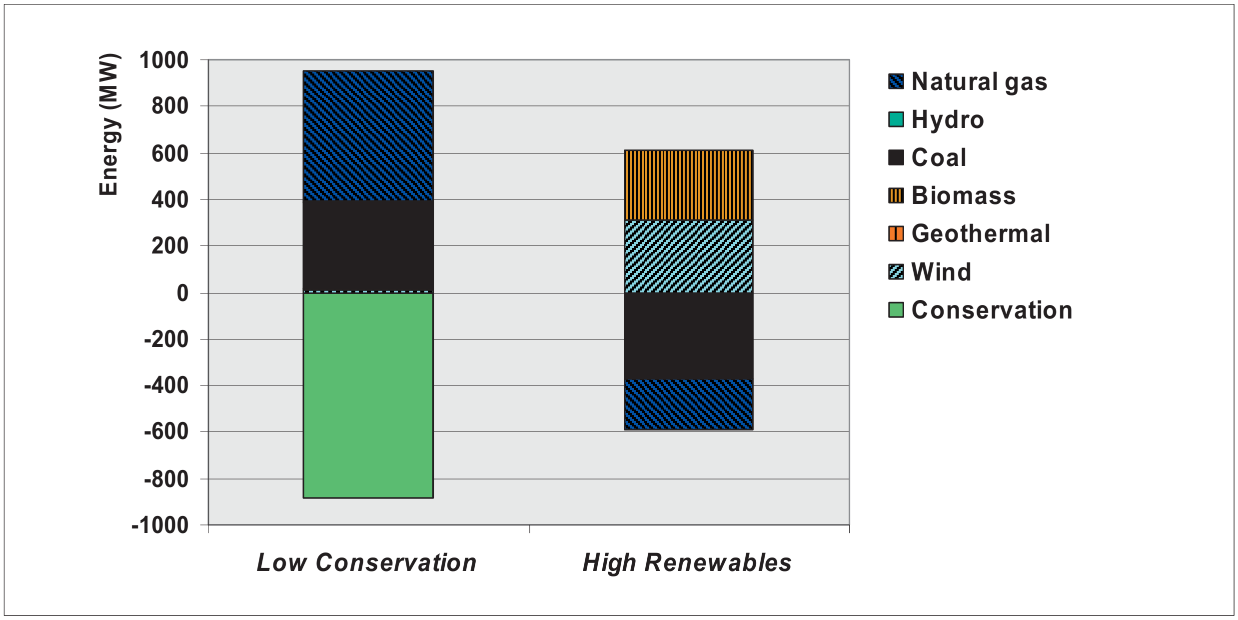

Figure 8: Average annual change in resource output vs. base case (WECC, 2015-24)

and 370 megawatts of gas turbines compared to the base case. The peaking capacity and energy balance of the base case was maintained by eliminating the 425 megawatts of new coal in the base case.

Effects of alternative resource-development scenarios

The production of CO2 is a function of the fuel and efficiency of resources dispatched to meet load. Alternative resource mixes will lead to changes in dispatch because of differing variable costs of operation and physical operating characteristics. Net changes for the entire WECC must be evaluated because of the effects of Northwest resources on resource dispatch in interconnected areas. A comparison of the average annual change in energy production by type of resource for 2015-24 for the two alternative resource-development scenarios compared to the base case is illustrated in Figure 8.

Low Conservation

Additional energy from coal (370 average megawatts) and natural gas (560 average megawatts) substitute for the reduced conservation of the low-conservation scenario. By 2024, annual CO2 production from Northwest sources would be 71 million tons per year (MMtpy), 4.4 million tons greater than the base case and a 61 percent increase over the 1990 rate. Annual net CO2 production for 2024 across the entire WECC system would increase 5.2 million tons compared to the base case, nearly the equivalent of two typical 400-megawatt coal-fired power plants. By 2024, this scenario includes about 770 fewer average megawatts of conservation than the base case. Each average megawatt of unachieved conservation would increase average net annual CO2 production by about 6,700 tons per year.

Wholesale power prices are forecast to be higher on average in the low-conservation scenario compared to the base case. Higher prices result from the dispatch of higher variable-cost resources, such as gas turbines to serve the additional load resulting from lower conservation achievement.

High Renewables

Additional energy from wind (310 average megawatts) and biomass (300 average megawatts) in the high-renewables scenario would reduce energy production from coal by 370 average megawatts and natural gas by 220 average megawatts. By 2024, annual CO2 production from Northwest sources would be 63 MMtpy, 4.2 million tons less than the base case. Although this would reduce the 2005-24 growth of CO2 production rates by 44 percent, the resulting rate still represents a 41 percent increase over the 1990 rate. Annual net CO2 production for 2024 across the entire WECC system would decline 5.1 million tons compared to the base case.

Wholesale power prices are forecast to be slightly lower on average in the high-renewables scenario compared to the base case. Lower prices result from the displacement of high variable-cost resources, such as gas turbines by the additional low variable-cost renewable resources of this scenario.

Removal of the Lower Snake River Hydroelectric Projects

Analysis of breaching the four federal hydroelectric projects on the lower Snake River[10] indicates the loss (on average under current river operations) of about 1,020 average megawatts of carbon-free energy and 2,650 megawatts of sustained peaking capacity. The impact of this loss on the production of CO2 depends on the nature of the replacement resources. The resource replacement depends on the particular resource-development strategy, as illustrated in the resource-development scenarios described earlier.

Resource replacement

Three possible approaches to replacing the reduced hydroelectric output of the dams were considered. These were: replacement with market purchases, replacement with natural gas resources, and replacement with conservation and renewable energy resources and natural gas capacity. The results of the second approach are reported because they are considered the most consistent with the base case and the Fifth Power Plan. Replacement with market purchases would compromise system adequacy and reliability by reducing the amount of resource available to meet load. Replacement of the power lost by breaching the lower Snake River dams by increased acquisition of conservation and renewable energy could, at least in the near term, delay some of the CO2 impacts of dam breaching. However, tying the increased development of conservation and renewables to dam breaching is misleading. If additional conservation and renewables are available and desirable, they should be pursued as part of a regional strategy to reduce CO2 emissions. Thus, the effects of changes in renewable development and conservation achievements have been addressed in the resource-development scenarios discussed earlier. Removal of the lower Snake River dams will not make additional CO2-free energy resources available to meet future load growth or retire any existing coal plants. More than 1,000 megawatts of emission-free generation eventually will have to be replaced unless the supplies of renewables and conservation are considered unlimited. Given the difficulty of reducing CO2 emissions, discarding existing CO2-free power sources has to be considered counterproductive

The lower Snake projects were assumed to ter-

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[10] The projects are Ice Harbor, Lower Monumental, Little Goose, and Lower Granite.

minate production on December 31, 2014, and replacement resources were assumed to commence operation on January 1, 2015. This permitted the development of 10-year (2015-24) averages consistent with the other studies of this analysis. Resource-development assumptions for WECC areas outside of the Northwest were held constant.

The analysis assumes that the average energy output of the projects is replaced by natural gas-fired combined-cycle plants. The balance of the sustained peaking capacity of the projects is replaced by natural gas-fired simple-cycle gas turbines. The combined capacity of three combined-cycle units (1,830 megawatts) and 18 simple-cycle gas turbine units (846 megawatts) slightly exceeds the sustained peaking capacity of the four hydro projects. The analysis did not address replacement of ancillary services such as regulation, load following, and power factor control provided by the projects.

Effects of lower Snake dam replacement

When the operation of the changed power system is simulated, the lost hydro energy is replaced with the additional production of 170 average megawatts from existing coal-fired units and about 810 average megawatts from new and existing natural gas units. By 2024, annual CO2 production from Northwest sources would be 70 MMtpy, 3.6 million tons greater than the base case and a 59 percent increase over the 1990 rate. Annual CO2 production for 2024 across the entire WECC system would increase 4.4 million tons compared to the base case.

A modest increase in wholesale power prices is forecast, resulting from replacement of the hydro energy with higher variable-cost thermal energy. Significant capital expenditures would be incurred for replacement resources and costs associated with dam removal, which would increase cost-based utility electricity prices. System reliability should be relatively unaffected because of the capacity value and energy capability of the replacement resources. While the supply of ancillary services should be unaffected because of the replacement capacity, ancillary service prices may increase because of the higher operating costs of the replacement thermal resources.

Summer Spill Operations

The summer spill program at the lower Snake River and lower Columbia River hydroelectric projects is intended to facilitate the downstream migration of anadromous fish. The original summer spill requirements date to the 1990s and were incorporated in the 2000 Biological Opinion (BiOp). The 2004 BiOp incorporated the summer spill operation of the 2000 BiOp with minor changes. In 2005 and subsequent years, summer spill was increased further by court order (Preliminary Injunctive Relief Operation). The base case (the Fifth Power Plan portfolio) is based on 2004 BiOp operations, and thereby represents an intermediate level of summer spill.

This study estimates the CO2 production impacts of the two summer spill regimes by comparing the average Western system dispatch and net CO2 production for no summer spill operation and court-ordered summer spill operation to the average Western system dispatch and net CO2 production of the base case (2004 BiOp). The comparison in all scenarios is average dispatch and CO2 production for the period 2015-24.

The base case is as described earlier and includes summer spill operation as called for in the 2004 Biological Opinion.

The no summer spill scenario is based on the energy shape and output of the hydropower system without summer spill at the lower Snake River and Columbia River projects. In all other respects, the scenario is identical to the base case. About 550 average megawatts of hydropower energy would be gained under this operation compared to the base case.

The additional court-ordered spill scenario is based on the energy shape and output of the hydropower system under 2006 court-ordered spill operation. In all other respects, the scenario is identical to the base case. About 360 average megawatts of hydropower energy are lost under this operation compared to the base case.

No summer spill

In the no summer spill scenario, the additional hydro energy would displace about 190 average megawatts from coal-fired power plants and about 330 average megawatts from natural gas power plants (Figure 9). This would reduce average annual CO2 production for 2024 from Northwest sources by 1.1 million tons compared to the base case (2004 BiOp). By 2024, 66 MMtpy of CO2 would be produced directly from Northwest sources, a 48 percent increase over the 1990 rate. Annual CO2 production for 2024 across the entire WECC system would decrease 2.4 million tons compared to the base case.

Sensitivity Cases

Comments on the draft of this analysis requested sensitivity cases on some of the basic assumptions used in all of the scenarios. These included the effects of higher CO2 costs, higher fuel prices, and wind variability.

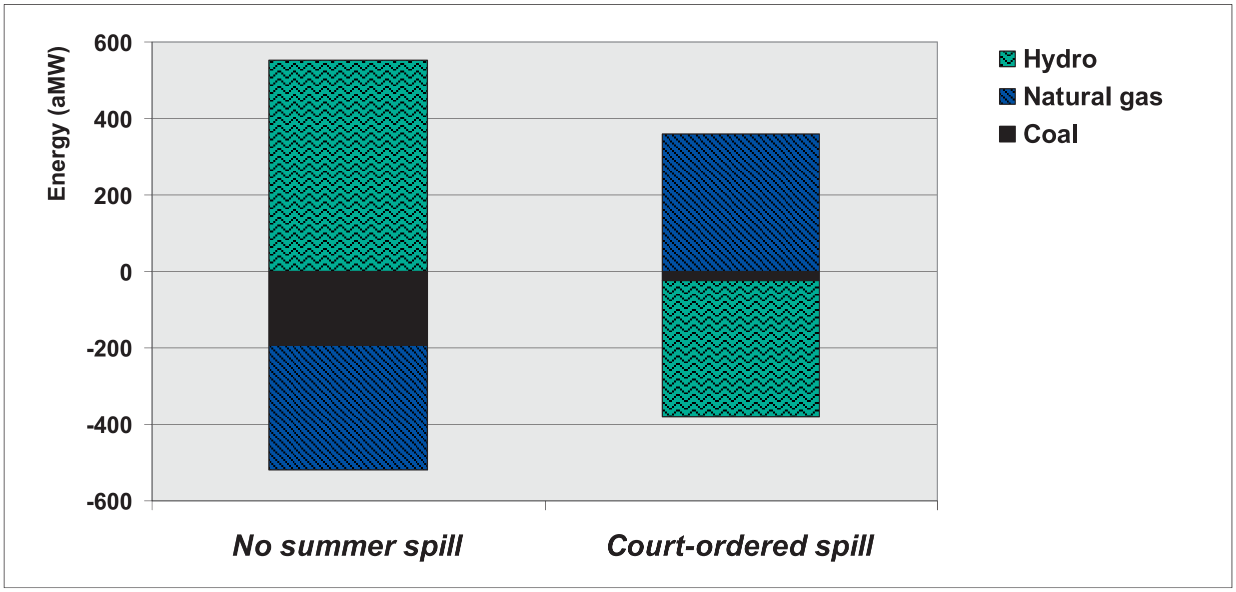

Figure 9: Average annual change in resource output vs. base scenario (WECC, 2015-24o

Court-ordered spill

About 20 average megawatts from coal-fired power plants and about 360 average megawatts from gas-fired power plants are needed to compensate for the lost hydro energy of the court-ordered spill scenario. This increases average annual CO2 production for 2024 from Northwest sources by 0.5 million tons compared to the base case (2004 BiOp). By 2024, 67 MMtpy of CO2 would be produced directly from Northwest sources, a 52 percent increase over the 1990 rate. Annual CO2 production for 2024 across the entire WECC system increases 1.5 million tons compared to the base case.

The overall effect of court-ordered spill compared to no summer spill operation within the Northwest is to increase the average annual CO2 production for 2015-24 by 2.1 million tons. For WECC as a whole, court-ordered spill increases average annual CO2 production 5.2 million tons compared to no summer spill operation.

Higher CO2 costs

All scenarios investigated in this study included the mean value CO2 prices from the portfolio risk assessment of the Fifth Power Plan. This price, representing a carbon tax or the cost of carbon allowances under a cap and trade system, appears in 2009 and gradually rises to about $9.00 per short ton of CO2 by 2024 (2006 dollars). A sensitivity case with doubled CO2 price was run to explore the possible effect of increased CO2 price on resource dispatch and CO2 production. The resource mix was held constant for this case, so the impacts of the higher CO2 prices are generally limited to shifting from coal to natural gas fueled plants. Higher power prices might also induce demand response and load curtailment.

With doubled CO2 prices, WECC-wide dispatch of coal declined 9 percent, with the difference largely met with increased dispatch of natural gas plants. A slight increase in demand response was also observed. Northwest CO2 production in 2024 does not significantly change from the base case, but for WECC in its entirety, 2024 CO2 production declined 9 million tons.

Higher fuel costs

All scenarios investigated in this study were based on the medium case fuel price forecast of the Fifth Power Plan. Current forecasts of fuel prices, including the recent revision of the Council's fuel price forecast, are generally higher than earlier forecasts, including that of the Fifth Plan. Though the Council's revised fuel price forecast had not been adopted when the base case analysis was under development, a sensitivity analysis was run using the medium-high fuel price forecast case of the Fifth Power Plan. North American wellhead gas prices in the Fifth Power Plan medium-high fuel price forecast are $5.20/MMBtu in 2024, compared to $4.60/MMBtu in the medium case (2006 dollars). The equivalent western mine mouth coal prices are $0.67 and $0.59 per MMBtu. The resource mix was held constant for this case, so the impacts of the higher fuel prices are generally limited to shifting between natural gas and coal. As in the higher CO2 price case, higher power prices might also induce demand response and load curtailment.

For WECC as a whole, the overall dispatch of coal and natural gas plants was essentially unchanged in the medium-high fuel price case. A slight increase in demand response was observed, as was increased dispatch of geothermal plants (geothermal plants are modeled as dispatchable with a variable fuel cost). Higher fuel prices did not significantly affect CO2 production in the Northwest or for WECC as a whole.

Windpower volatility and intermittency

Wind is currently modeled in AURORA with a flat energy output equivalent to annual capacity factor. A sensitivity case in which the hourly intermittency of wind was modeled using historic hourly output of several geographically diverse Northwest wind projects resulted in an insignificant change in CO2 production. Further testing of the impact of hourly intermittency may be desirable as more extensive actual and synthetic wind output data becomes available from the Northwest Wind Integration Action Plan.

Though hourly wind volatility did not significantly affect CO2 production in this sensitivity case, it is possible that sub-hourly wind volatility might impact CO2 production. In the later years of the study period, increasing loads and higher levels of wind penetration may increase the demand for regulation and load following services beyond the capability of the hydro system to provide these services. Fossil resources such as simple-cycle gas turbines may be called upon to provide regulation and load following, which would increase CO2 production.

Achieving Significant Reductions in CO2 Production

The findings described in this paper illustrate the difficulty of reducing CO2 production to rates considered necessary for climate stabilization. Current rates of conservation acquisition, and policies such as renewable portfolio standards mandating acquisition of low carbon resources, will help reduce growth of CO2 production. However, as discussed earlier, these activities are likely to be insufficient to maintain current levels of CO2 production, much less to reduce CO2 production to levels sought by greenhouse gas control policies. Achieving these goals will require deep cuts in the CO2 production from existing fossil plants or equivalent offsets from other sectors or geographic areas.

To give some perspective to the challenge of meeting proposed CO2 reduction targets, we have calculated the amount of CO2 emissions that would need to be reduced from the base case (Fifth Power Plan) forecast for 2020. Two cases are illustrated to give some perspective on the size of the challenge. One is the Western Climate Initiative (WCI) target of reducing CO2 emissions to 15 percent below 2005 levels by 2020. Another is to reach 1990 levels by 2020, which is both Washington's target and the target in the proposed Lieberman-Warner "America's Climate Security Act."

Assuming the Northwest power system met similar percentage reductions in its 2020 CO2 emissions, what is the magnitude of the reduction in terms of million tons per year and how can that be put into perspective?

Taking the WCI target first, the required reductions would depend on how the 2005 CO2 emissions were determined. As illustrated earlier, 2005 was a poor water year. Actual CO2 production from the power system was estimated to be 67 million tons per year. The WCI target, if based on actual emissions, would be 57 million tons per year. To reduce the base case forecast of CO2 production in 2020, which is 65 million tons, down to actual 2005 levels would require a reduction of 7 million tons of CO2. However, if based on normal hydro conditions, the WCI target would be 48 million tons per year. Achieving a WCI target based on normal hydro would require a reduction of 17 million tons.

One way to put this into perspective is to calculate how much coal capacity would have to be replaced with a carbon-free source or with conservation, as shown in Table 2. More existing capacity than indicated in the table would require replacement if a portion of the replacement resource were low-carbon, such as coal gasification plants with partial CO2 separation and sequestration. Further analysis would be needed to estimate the amount of replacement capacity needed, as this depends on the CO2 and economic characteristics of the replacement resources.

Policy	2020 Target (MMtCO2)	Reduction Needed (MMtCO2)[11]	Equivalent Coal Capacity (MW)
WCI - 15% below actual 2005 by 2020	57	7	910
WCI - 15% below normal 2005 by 2020	50	17	2330
WA - 1990 by 2020[12]	44	21	2780
OR - 10% below 1990 by 2020	40	25	3300

Table 2: CO2 reductions from base case (Fifth Power Plan) forecast to achieve various 2020 policy targets

A multipronged effort is required for the industry to cost-effectively achieve the goals of greenhouse gas control policies.[13] This effort must include the following elements:

- Reduction in demand through more aggressive improvements in end-use efficiency.
- Shifting new resource acquisitions to low-carbon resources.
- Reducing the CO2 production of existing fossil generation through efficiency improvements, carbon capture and sequestration, and substituting low-carbon baseload generating capacity.
- Marketing and credit transfer mechanisms to help secure CO2 reductions in other economic sectors and geographic areas where cost-effective.

In short, achieving greenhouse gas control targets economically requires broadening cost-effective resource planning and acquisition to consider a global scope of CO2-reduction options.

While developing mechanisms to facilitate cost-effective global CO2 reduction lies largely outside the control of the Northwest power industry, the following options can be cultivated within the industry:

Expand the supply of cost-effective energy-efficiency measures: An expanded inventory of end-use efficiency options will reduce the growth in demand for electricity, thereby reducing CO2 production from generating resources. Historically, conservation has been among the most cost-effective and abundant of new resource options. New conservation opportunities have continued to unfold even as older opportunities are developed. Production of CO2 from power generation can be reduced by aggressive implementation of existing conservation measures and development of new measures with a focus on those most effective during the hours that CO2 -intensive generating resources are on the margin.

Existing low-carbon generating resources: The efficiency, energy output, and operating life of existing low-carbon resources can be improved. For example, each percentage point increase in the capacity factor of Columbia Generating Station will offset approximately 0.05 million tons of CO2 per year.[14] Opportunities to improve the efficiency and capacity, and extend the life of the region's existing biomass, hydropower, and nuclear resources can be explored and pursued where cost-effective.

New renewable generation: Expanding the supply and improving the cost-effectiveness of new renewable resources involves concurrent efforts: First, the

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[11] Reduction from base case (Fifth Power Plan) 2020 forecast.
[12] Also the target of the proposed Lieberman-Warner America's Climate Security Act.
[13] A recent study by the Electric Power Research Institute provides a very useful illustration of the challenge to significantly reduce power system CO2 emissions. See EPRI, "The Power To Reduce CO2 Emissions: The Full Portfolio," August 2007.
[14] Based on an average systemwide marginal CO2 production rate of 0.9 lb/kWh as estimated by the Council ("Power System Marginal CO2 Production Factors," Northwest Power and Conservation Council, April 2006).

supply of regulation, load following, shaping, and storage capability needed for integrating intermittent resources such as wind, tidal currents, wave, and solar need to be expanded through the development of improved methods of marketing and transferring these services within the existing system. Because the supply of these services will eventually need to be augmented, options for supplying these services, including generation, storage, and load-side proposals such as plug-in hybrid vehicles need to be better understood. Secondly, the capacity of the existing transmission system to serve new renewable resources needs to be expanded by developing products such as a conditional-firm service that more effectively utilizes the existing transmission capacity. New transmission will be needed to serve increasing amounts of remote renewable capacity and to improve the geographic diversity of wind and other intermittent renewable resources. Mechanisms are needed to facilitate planning, financing, and construction of new transmission, including "merchant" transmission primarily serving new resources. Finally, new renewable resources and technologies, including wave and tidal current power production, low temperature and engineered geothermal resources, dedicated energy crops, and more efficient biomass technologies need to be developed.

New fossil generation: Even with aggressive conservation measures and an expanded supply of renewable resources, new, lower-carbon fossil generation may be the most cost-effective source of baseload power. Moreover, gas turbines may be needed to augment the supply of integration services for intermittent renewable resources. Improving the efficiency of conventional gas turbine and pulverized-coal power plants, and commercializing coal gasification and other advanced coal technologies will extend fuel supplies and lower CO2 production at the source.

Carbon capture and sequestration: CO2 capture technology suitable for coal gasification plants is commercially available. However, while technically feasible, CO2 capture for conventional and advanced coal-steam plants and gas turbine plants is at the early demonstration stage. Development and commercialization of CO2 capture technology for all forms of fossil generation need to be accelerated to provide options for both new and retrofit applications.

Bulk CO2 transportation and sequestration has been demonstrated for depleted oil and gas reservoirs. While some oil and gas reservoirs are present in Montana, a greater potential in the Northwest are the basalt flows of the Columbia Basin and Snake River Plain. Additional Northwest potential may be available in deep coal seams, carbonate saline aquifers, oceanic storage, and soil carbon sequestration in croplands, grazing lands, and forests. Work needs to proceed on investigating and field-testing promising sequestration options for the Northwest.

New nuclear generation: A new generation of nuclear plants could provide bulk quantities of carbon-free baseload power. Approximately 30 new nuclear units are proposed for construction in the United States. The license application for the first two has recently been filed with the Nuclear Regulatory Commission and license applications for additional units are expected in 2008. While the first new units completed are likely to be located in the Southeast (a region with less favorable renewable resource potential than the Northwest) and not be completed until 2014-15, new nuclear plants may become attractive to the Northwest once new units are successfully operating and resolution of the spent fuel disposal issue is achieved.

Appendix A: Methodology and Analytical Issues

The CO2 production of each scenario was forecast using the AURORAxmp™ Electric Market Model. Though primarily used to forecast wholesale electricity prices, AURORA is also capable of forecasting pollutant emissions and CO2 production resulting from system operation. AURORA forecasts power prices by simulating the economic dispatch of individual generating units as needed to meet system load. Fuel consumption is tracked because fuel prices are a major component of the variable cost of electricity production with which plant dispatch is evaluated and power prices determined.

CO2 production was calculated using the following emission factors: natural gas 117 lb/MMBtu, fuel oil 166 lb/MMBtu, coal 212 lb/MMBtu, and petroleum coke 225 lb/MMBtu. Complete conversion of fuel carbon to CO2 was assumed. Biomass fuels, including municipal solid waste, are assumed to produce no net CO2. While some of the combustible content of municipal solid waste fuels is of petroleum or non-closed carbon cycle derivation, the small consumption of municipal solid waste for power production in the

Northwest has a negligible effect on net CO2 production. The CO2 output of fossil-fueled cogeneration units is based on "fuel charged to power" heat rates—the portion of fuel consumption attributable to electricity production.

With the exception of a sensitivity analysis on water conditions, described later, this work was based on 50-year average hydropower conditions, the medium-case fuel price forecasts, and the medium-case load growth forecasts of the Fifth Power Plan. As a result, the CO2 production forecasts are representative of long-term averages (to the extent that forecast fuel prices and demand are realized). Actual CO2 production will vary from the average depending on hydropower conditions, actual fuel prices, and actual loads. As illustrated earlier in Figure 2, CO2 production is sensitive to hydropower conditions, including runoff patterns. In general, hydropower displaces more thermal energy in good water years than in poor. Heavy spring runoff may displace coal-fired power plants during light springtime load periods, whereas delayed runoff may displace natural gas combined-cycle plants during heavier early summer loads. While economically beneficial because of the higher cost of natural gas, the later runoff would have less impact on CO2 production because of the lower carbon content of natural gas and the higher thermal efficiency of combined-cycle plants.

A question has been raised regarding the symmetry of the incremental effects on CO2 production of good and poor hydropower years of equal probability. If incremental CO2 production effects are not symmetrical, the estimates reported here may be biased, as they are based on average water conditions. A comparable effect has been observed, and is adjusted for, in the Council's electricity price forecasting. While time did not permit comprehensive testing, a limited comparison of forecast CO2 production in a very good water year to that of a very poor water year indicated a slight increase in the incremental CO2 production for the poor water year compared to the good water year. While further analysis would be required to confirm the consistency and magnitude of this effect, if true, the CO2 production estimates reported in this paper would tend to be slightly low.

The geographic scope of the analysis is the WECC interconnected system. Northwest resource development and operational decisions result in operational effects outside the Northwest because of transmission interconnections and Westwide markets. For this reason, CO2 production results are reported on a WECC basis. "Northwest" results, where reported, include the CO2 production of units physically located within the four Northwest states, plus the production from large thermal units outside the region dedicated to serving Northwest loads. These include the Jim Bridger plant in Wyoming and the Idaho Power share of the North Valmy plant in Nevada.

The net changes in CO2 production estimated in this study are the direct effects of power plant fuel consumption. Secondary impacts, not assessed here, may be present (e.g., CO2 from diesel oil combustion for the rail transportation of additional coal).

Price elasticity may result in reduction of demand due to higher prices caused by carbon taxes, higher-cost low carbon resources, cost of CO2 allocations, or other factors associated with climate change and policies addressing climate change. While the evaluation of this is beyond the scope of the current study, price elasticity will be considered in the Sixth Power Plan.

California, Oregon, and Washington have adopted policies prohibiting the long-term acquisition by utilities of resources or resource output where the associated CO2 production exceeds certain defined levels (generally exceeding the CO2 production of a natural gas-fired combined-cycle plant). Partial account of these carbon content policies is included in current analysis by permitting no new conventional coal plants to be located in California, Oregon or Washington when using the AURORAxmp capacity expansion feature. However, because AURORAxmp does not permit differentiation by resource type of economic inter-regional transfers, there appears to be no effective method of modeling carbon content policies.

Sufficient simple or combined-cycle gas turbine capacity was added in each scenario to maintain the pilot capacity reserve targets of the Resource Adequacy Forum. (The capacity value of wind power was set at 15 percent for these assessments.) This gas turbine capacity would also provide "system flexibility" suitable for integrating intermittent resources. However, it will not be possible to accurately estimate the amount of flexibility augmentation needed to accommodate the intermittent resources of these portfolios until the capability of the existing system to provide intermittent resource integration is better understood. Estimates of the intermittent resource integration capability of the existing system are being refined as part of the Northwest Wind Integration Action Plan. The needed capacity composition of future resource portfolios can be refined as better estimates of the capabilities of the existing system (and likely flexibility demands of future intermittent resources) become available. This information may also support estimates of the likely CO2 production resulting from possible operation of fossil capacity for intermittent resource integration purposes.

Appendix B

	Conservation (aMW)	Coal (MW)	Gas (MW)	Hydro	Wind (MW)	Other (MW)
2005	96		178 (SC)		300	(26) Oil
2006	136	109 (PC)	47 (SC)	14 Hyd (26) Hyd	487	10 Geo 12 Bio
2007	139		745 (CC)	2 Hyd (29) Hyd	440	20 Bio (32) Oil
2008	147		650 (CC)	(23) Hyd		
2009	150			(23) Hyd		
2010	159			(23) Hyd		
2011	161			(23) Hyd	100	
2012	169			(23) Hyd	900	
2013	172			(23) Hyd	400	
2014	176			(23) Hyd	600	
2015	378			(23) Hyd	300	
2016	185	425 (IGCC)		(23) Hyd	1200	
2017	105			(23) Hyd	600	
2018	93			(23) Hyd	400	
2019	89		184 (SC)	(23) Hyd	200	
2020	86		610 (CC)	(23) Hyd	100	
2021	85		644 (SC)	(23) Hyd	300	
2022	84			(23) Hyd	100	
2023	86		276 (SC)	(23) Hyd	100	
2024	85		276 (SC)	(23) Hyd	900	

Table B1: Pacific Northwest resource development schedule for the base case (MW)[15]

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[15] Values in brackets are retirements.

Northwest
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EXHIBIT B

INDEPENDENT SCIENTIFIC ADVISORY BOARD

Review of the Proposed Spill Experiment

February 20, 2014
ISAB 2014-2

Independent Scientific Advisory Board
for the Northwest Power and Conservation Council,
Columbia River Basin Indian Tribes,
and National Marine Fisheries Service
851 SW 6th Avenue, Suite 1100
Portland, Oregon 97204

ISAB Members

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Kurt Fausch, Ph.D., Professor of Fisheries and Aquatic Sciences, Department of Fish, Wildlife, and Conservation Biology at Colorado State University

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Bonnie McCay, Ph.D., Board of Governors Distinguished Service Professor at Rutgers University, New Brunswick, New Jersey in the Department of Human Ecology of the School of Environmental and Biological Sciences

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Cover photo: McNary Dam spillway by Tony Grover.

ISAB Review of the Proposed Spill Experiment

Contents

ISAB Review of the Proposed Spill Experiment

Review Charge

On December 16, 2013, the Northwest Power and Conservation Council requested that the ISAB review the spill experiment proposed by the State of Oregon, the Nez Perce Tribe, and others for inclusion in the Council's Fish and Wildlife Program. The Council asked that the ISAB consider the following questions:

1. Is the spill experiment proposal, and the postulated increases in fish survival, consistent with scientific methods?[1]

   (a) Does the experiment include an adequately researched hypothesis?
   (b) Is the experiment appropriately designed to test the hypothesis?
   (c) Is the proposed duration of the experiment sufficient?
   (d) Is it possible to isolate spill as the causative factor for changes in fish survival?

2. If not, what adjustments will ensure that the proposal is scientifically based?

3. What are the potential biological risks and/or benefits, particularly focusing on increased total dissolved gas effects on other aquatic species, associated with the proposal?

4. Is the proposed spill experiment likely to add to our existing knowledge regarding spill, juvenile dam passage survival, and adult fish returns (SARs)?

Background

The Council provided the following background information in their review request to the ISAB:

> As part of the Fish and Wildlife Program amendment process, the Council received recommendations, based on CSS studies, from Oregon Department of Fish and Wildlife (ODFW), the Nez Perce Tribe (NPT), the Pacific Fishery Management Council (PFMC), environmental and fishing groups, and individuals calling for implementation of an experimental spill management test. This proposal would increase spring spill levels at each mainstem federal Snake and Columbia River hydropower project up to 125% of total dissolved gas level in the tailrace of each dam or biological constraints, and then monitor survival effects over ten years compared to the current court-ordered spill program. Since 125% total dissolved gas exceeds the Clean Water Act water quality standard, modifications to the standard through regulatory processes by the states of Washington and Oregon would be required.

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[1] The ISAB changed the wording of the Council's question from "the scientific method" to "scientific methods."

As proposed, the key elements of the experimental spill management would include:

1. Implementing voluntary spill levels greater than historical levels, particularly in lower flow years. Implementation is proposed to include these facets:
    - What: Increase spill to 125% of total dissolved gas level or biological constraints. As 125% total dissolved gas exceeds water quality criterion, criteria modifications through regulatory processes are required.
    - When: During spring operations (3 April through 20 June) for a period of 10 years with a comprehensive assessment after 5 years.
    - Where: At federal Lower Snake and Lower Columbia River Hydroelectric projects – Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles and Bonneville dams.
2. Utilizing the Comparative Survival Studies (CSS) PIT-tag monitoring framework.
3. Monitoring Smolt-to-Adult survival rates.
4. Comparing survival rates against both past survival rates and prospective model predictions.
5. Evaluating whether empirical observations are consistent with the predicted benefits of higher voluntary spill levels.
6. Inclusion of sideboards or "off-ramps" to ensure hydrosystem power generation viability as well as "on-ramps" that facilitate non-hydro renewable energy sources into the power system to offset impacts from increased spill levels.

Review Approach

To conduct the review, the ISAB received briefings and reviewed scientific documents explaining, supporting, and critiquing the spill study. On November 15, 2013, the Comparative Survival Study (CSS) team presented analyses related to the spill test to the ISAB. This presentation was part of the ISAB's ongoing role in reviewing CSS and Fish Passage Center reports and analyses, primarily annual reports. This presentation occurred before the Council's December 2014 review request but proved effective in introducing the ISAB to the spill study and supporting analyses. On January 17, 2014, the Bonneville Power Administration (BPA) and the U.S. Army Corps of Engineers (COE) briefed the ISAB on the performance standards, monitoring efforts, and study results related to dam and reach specific survival. Dr. John Skalski also briefed the ISAB on the results of his statistical analysis of the proposed spill test. The ISAB created a file accessible to the public containing the ISAB's review materials. This proved effective in creating a dialogue and facilitating sharing of literature among the ISAB and entities involved in salmon passage studies, hydrosystem operations, and dissolved gas regulation. The ISAB greatly appreciates the briefings, literature shared, and robust exchange of information.

Overview

Potential Biological or Other Benefits

- Prospective modeling of the proposed spill test by the CSS team suggests that increasing spill levels up to 125% total dissolved gas may enable smolt-to-adult-return ratios (SARs) to reach the 4% biological goal for steelhead and approach the 4% goal for Chinook.
- Knowledge gained through experimental spill management could be generalized to inform operations at other dams.

Potential Biological or Other Risks

- The spill test may *not* result in increased SARs as the justification for the proposed test is based on correlative models that do not establish causality.
- There may be inadequate information gained to justify the cost due to study design limitations and lack of a detailed study and monitoring plan.
- The spill test could result in unintended consequences, including:
    - greater adverse gas bubble disease (GBD) effects on salmonids, native resident fish and/or aquatic life;
    - increased delay and/or predation of juvenile fish in tailraces;
    - increased fallback and/or passage delays of adult salmon at the dams;
    - difficulty in holding spill levels at desired levels, for example in a low water year;
    - increased spillway erosion problems;
    - possible navigation issues for commercial and juvenile fish transportation barges at dams;
    - possible effect on Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp) operations or smolt transportation actions because increasing spill will reduce the number of fish collected for transportation;
    - future engineering changes to juvenile fish passage at dams could confound results from this spill test.

Additional Issues

- A detailed study plan needs to be developed by the proponents. The lack of details and lack of synthesis in the material presented leads the ISAB and others to raise questions (see unintended consequences listed above) that might have otherwise been addressed if a comprehensive study plan was developed.
- The Oregon and Washington water quality standards for total dissolved gas (TDG) would need to be modified with NOAA Fisheries concurring.
- Regional work and agreement would be needed on:
    - the study design including how long the test should run to provide convincing evidence of an increase in SARs that is due to increased spill;
    - an monitoring and evaluation plan for TDG, biological and physical parameters; and
    - changes to dam-specific spill patterns.

ISAB Answers to Council Questions

1. **Is the spill experiment proposal, and the postulated increases in fish survival, consistent with scientific methods?**

(a) Does the experiment include an adequately researched hypothesis?

The spill experiment proposal does not provide enough evidence for the ISAB to conclude that the experiment includes an adequately researched hypothesis. A complete study design, including detailed hypotheses and review of the literature, was not presented to the ISAB. Additional effort is needed to fully vet the experimental spill hypotheses and methodology. An action of this importance requires development of a complete description of the study design that addresses issues presented in this ISAB review and those raised by other stakeholders in the region (Skalski et al. 2013; BPA/COE 2014 and Skalski 2014, presentations to the ISAB).

The effects on salmonids of passing through dam spillways, turbines, and fish bypass routes have been investigated for decades including analyses by CSS that are documented in annual reports and peer-reviewed publications, reach survival studies by NOAA Fisheries, and dam passage survival evaluations by the Corps of Engineers. The results of these studies need to be synthesized and integrated into a more complete proposal as a means to evaluate the regression analyses and modeling presented by the CSS.

In the proposed spill test, recent regression analyses (Haeseker et al. 2012) are used to support the hypothesis that an increased percentage of water spilled over dams leads to higher survival of in-river migrants. Presumably, the experimental spill hypothesis is that increasing spill targets up to 125% TDG will lead to higher SARs of spring-summer Chinook and steelhead compared with SARs observed in years leading up to the spill test period, after adjusting for confounding variables such as ocean conditions and other juvenile fish passage improvements at the dams. Simulation modeling, based on recent peer-reviewed models and assumptions within, suggests that increasing spill levels up to 125% TDG in each of the dam tailraces would lead to considerably higher SARs of spring-summer Chinook and steelhead compared with observed SARs and SARs estimated based on simulations of BiOp operations (see Fig. 1 below from Schaller PPT to ISAB, Nov 15, 2013). This modeling effort, based on existing data, should be used to establish specific quantitative hypotheses for testing. The model simulations should be updated with recent years of data prior to beginning the potential spill test. Furthermore, the degree to which the hypotheses rely on extrapolation should be discussed. For example, in the published modeling reports, how frequently were SAR estimates available when spills were at or near 125% TDG? Also, it may be worthwhile to compare model predictions with expectations from studies directly examining survival of salmonids passing through spill, turbines, and the bypass system (Muir et al. 2001, Marotz et al. 2007, WA Dept. of Ecology 2008). The extent to which results from the CSS simulation studies are consistent with the findings in other studies should be evaluated.

Further scrutiny of the analyses and interpretation of the data and models used to justify the spill test is warranted. The spill test was generated primarily in response to regression models that showed that changes in spill percentage were correlated with increases in SARs. There is a potential problem in using the results of a regression equation as the basis for an experiment, especially if sample sizes are small. Regression models based on small sample sizes often overfit the data so the resulting relationships are not applicable to other sets of data. Selection of explanatory variables for multiple regressions must be carefully considered (Skalski et al. 2013) and the resulting models should be interpreted with caution. That said, six freshwater and marine variables examined by Haeseker et al. (2012) – water transit time (WTT), spill, date of migration, upwelling, sea surface temperature (SST), and Pacific Decadal Oscillation (PDO) – had all been identified as important in other studies, so the choice of these variables has support in the literature (Muir et al 2001, Scheuerell and Williams 2005, Schaller and Petrosky 2007, Petrosky and Schaller 2010). Nevertheless, to address alternative hypotheses additional candidate variables need to be evaluated, for example, biological measures of top-down (predation) and bottom-up (primary and secondary productivity) forcing, individual fish (age, growth, and condition), density-dependent effects, and anthropogenic forcing (habitat, harvest, and hatchery).

Some of the explanatory variables in the model operate at the year level (e.g., PDO, upwelling and SST) whereas others operate at the week or period of release level. A more complex model including multiple random effects is likely needed to fully account for the internal correlation structure. By ignoring the multi-level variation, estimates of residual error are likely underestimated, which also may lead to errors in model predictions.

It is assumed that the survival rate experienced by each release group within a year was independent of survival rates experienced by other groups within the same year. However, in reality, survival rates are likely correlated among groups within the same year, as well as autocorrelated over time. Such correlations reduce the effective sample sizes in tests of statistical significance, and failure to account for these effects will increase the uncertainty of the model predictions. The Durbin-Watson test is not appropriate to evaluate autocorrelation as it fails to account for the two levels of explanatory variables needed in the model.

Despite these concerns with the statistical analyses used to support implementation of the spill test, it appears that the increased spill hypothesis stands as a possible candidate for testing. Other changes to hydrosystem operations have so far been inadequate to meet SAR targets required to conserve endangered salmon populations, even with structural changes that have been made at the dams such as surface spill weirs. It appears that increasing the amount of water spilled at lower Columbia and Snake River dams has merit as a hypothesis to test, but additional review of literature and analysis of data would be worthwhile.

Increasing spill is expected to allow a greater proportion of migrants to avoid the powerhouse intakes and speed their migration through forebays. It is uncertain if the proportion of fish that avoid powerhouse intakes continues to increase as spill increases, and how this proportion is affected by changes in flow. That is, how does each project’s spill efficiency change with changing flow conditions, and is there a point of diminishing returns in terms of spill and percentage of fish passed over the spillway?

Hypotheses should be developed for how increasing spill levels will affect returning adult salmonids, downstream-migrating steelhead repeat spawners (kelts), adult and juvenile lamprey, and sturgeon that may be influenced by TDG and changes in hydraulic flow patterns at the dams. The level of effort to monitor gas and adult migration effects would depend on a review of the literature and resulting uncertainty about potential adverse effects. The CSS and others presented the ISAB with some ongoing review of TDG effects, but this information should be summarized and presented in the proposal. As well, the spill test should consider whether effects from the proposed increase in spill might compromise the results from other ongoing studies in the basin.

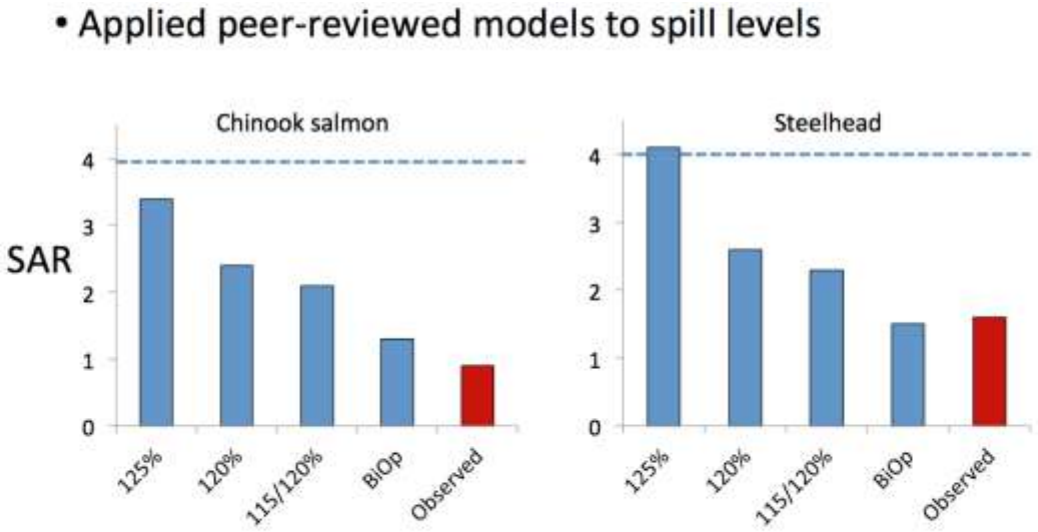

Fig. 1. Modeled SAR estimates of spring Chinook and steelhead in relation to spill levels, based on recent publications by CSS members. Source: Schaller PPT to ISAB, Nov 15, 2013. These charts presumably describe the spill hypothesis. Values in these charts should be updated with the latest data.

(b) Is the experiment appropriately designed to test the hypothesis?

Details of the proposed experiment are not adequately described or documented in a written proposal, so it is premature for the ISAB to determine if the study design is appropriate. First, as discussed above, the specific hypotheses to be tested are not adequately described. Second, due perhaps to practical limitations in devising controls for treatments, what is proposed is not a rigorous experiment but a test of a management action whose effects, ideally, will be evaluated.

It is not clear why a more rigorous experiment with controls has not been proposed. The proposed action is limited to levels of spill at each dam which result in 125% TDG in the tailrace rather than to vary the spill more systematically or consider designing a regime of alternating high/low spill years. This proposal does not discuss the merits of alternative designs, for example varying the level of spill in some years or split-spill studies where only some dams have increased spill. Such a discussion would illustrate the constraints under which such experiments operate and why some may not be feasible. If these and other experimental designs have been considered and discarded, then these efforts should be noted and the reasons for dismissing them identified.

A problem in comparing SARs during the experimental period (with spill targets set at 125% TDG) to SARs during the pre-spill test period is that the pre-spill test period may not be an adequate control because ocean and environmental conditions are likely to be considerably different. Ocean conditions have a major impact on SARs beyond in-river factors. The models attempt to account for ocean effects with independent variables such as the PDO, but considerable variability undoubtedly remains, which will lower the power and reliability of the test. The CSS may be aware of this, but it would be worthwhile to discuss the issue in a proposal and justify the use of SARs to assess results and testing hypotheses in a realistic time frame. Presumably, in-river survival also will be measured, as in past CSS studies. In-river survival estimates are more direct measures of the spill effect, though they cannot detect changes in delayed mortality.

Multiple lines of evidence based on different approaches should be considered. SARs for John Day, Mid-Columbia, and Snake populations could be compared to better estimate the magnitude of the effect of higher spill on reach survivals and SARs. SARs for John Day River populations (passing 3 dams) and Snake River populations (passing 8 dams) were previously compared to infer the deleterious effects of dams. Although this historical comparison was potentially confounded by other factors associated with location in the basin and stock differences, an experimental contrasting manipulation of spill levels that changed SARs in the predicted direction would provide some evidence of the influence of spill. In addition, other modeling approaches should be considered such as using the ratio of SAR for transported fish to SAR for in-river fish (TIR). Although transported fish are influenced by in-river conditions upstream of the transportation collection site and below Bonneville Dam that are positively correlated with percentage spill, most of these fish do not directly experience any spillway passage.

The proposed study offers an opportunity to use adaptive management that might improve SARs of threatened and endangered salmon ESUs and increase knowledge for future decisions. This situation seems to fit the criteria for true adaptive management, as outlined in papers like those by Kendall (2001), Runge (2011) and Tyre et al. (2011). First, there is certainty about the goal (increase SARs), but uncertainty remains about the ecological in-river and ocean survival processes that affect SARs. Therefore, the project should be designed to reduce critical uncertainties. Second, there are competing models that make contrasting predictions. Alternative actions could be identified and applied, and then the models updated periodically, using for example Bayesian analysis, leading to learning that feeds back to management.

(c) Is the proposed duration of the experiment sufficient?

The question of whether the study duration is sufficient to conclude that increased spill to the 125% TDG provides a meaningful increase in SARs for spring/summer Chinook and steelhead should be evaluated by the CSS in a study proposal. Existing data and hypothesized effects can be used to evaluate whether 10 years is adequate.

Ocean conditions are not controllable, so some estimate of the expected change in SARs due to increased spill under poor, average, or good ocean conditions is needed. For example, suppose that a warm phase of the PDO was to begin at the start of the test and last for many years. Or, what if a PDO regime shift occurs several times during the 10-year study period? Would this improve or hinder the chances of detecting effects after 10 years?

(d) Is it possible to isolate spill as the causative factor for changes in fish survival?

It is unlikely that overall changes in SARs can be isolated to conclude that spill is the causative factor for the system. The CSS approach uses correlations which do not by themselves determine cause and effect. There are many confounding factors and indirect effects of spill on fish survival including predation and other mortality in the reservoirs, deployment of new spillway weirs, delayed mortality, ocean conditions, habitat restoration activities, changes in toxic contaminants and other factors.

Nevertheless, multiple lines of evidence including correlations can help support or refute whether spill is a major factor affecting survival of salmonids. Experimental studies in the Basin provide additional information on survival of salmonids passing through spill versus turbines versus the turbine bypass (e.g., Muir et al. 2001). What do these experimental studies tell us and are differences in survival consistent with the CSS study results?

2. If not, what adjustments will ensure that the proposal is scientifically based?

The proponents should be encouraged to prepare a more complete and detailed proposal that addresses issues and concerns that have been put forward by the Action Agencies and stakeholders, partly because details of the study have yet to be described in a document. Several iterations of the proposal may be needed to fully vet issues while providing a rigorous scientific review. The main conceptual issues are 1) lack of an experimental control group, and 2) low statistical power to detect effects given empirical estimates of variation in survival estimates and the survival process itself.

The ISAB appreciates that some options for improving whole system survival cannot be tested with rigor because of practical limitations (they lack controls and sufficient power or sample size). However, such limitations should not, in principle, negate consideration of less rigorous tests. Regardless, proposed actions and monitoring opportunities should be thoroughly considered, with strong adherence to a strategy for adaptive management. Development of a detailed monitoring plan is recommended and needed, especially for areas of high uncertainty, such as the following:

(a) improving detection rates to get better estimates of smolt survival estimates through the hydropower dams and reservoirs. Estimates of the survival of juvenile fish passing the dams via spill or other passage routes are available through COE funded acoustic tag (JSATS) studies of dam passage survival, although dam performance standard studies are not conducted every year. Association of direct juvenile survival past dams with spill should be discernible with appropriately designed monitoring;

(b) monitoring to assess condition of juvenile fish after various passage options to see if the increased spill is having a detrimental effect on fish condition. The issue of possible selectivity of the bypass system whereby fish that enter the dam bypass facility may be injured or somehow weaker than those that pass dams through other passage routes should also be examined;

(c) monitoring of adult salmonids, steelhead kelts, and other fish and other aquatic life to determine the impact of a long period of increased spill and increased total dissolved gas;

(d) evaluation of the proportion of fish passing via spill and all other routes with increased spill;

(e) evaluation of the effect of increased levels of spill on upstream passage of adult fish. New spill patterns could be tested in the hydraulic scale models at Vicksburg and also monitored at the dams during the spill period. Advance testing of the effects of increased spill in hydraulic scale models would be useful not only for estimating impact on upstream fish passage but also for identifying paths that juvenile fish might prefer and to reduce predation risk to juvenile fish in downstream eddies and tailwaters;

(f) related to (d), monitoring predation risk of fish in relation to increased spill;

(g) at this time models probably cannot predict fish survival at 125% TDG levels since empirical data on such high spill levels over the 2.5 month spring migration period are not available. However, collecting appropriate data that can be used in models will enable predictions in the future.

3. What are the potential biological risks and/or benefits, particularly focusing on increased total dissolved gas effects on other aquatic species, associated with the proposal?

The proposed spill test should consider the potential impact on other species, such as fall Chinook and sockeye salmon, sturgeon, lamprey, and other aquatic life. Hypotheses should be developed on how spill maintained at 125% TDG for several months might affect each species and life stage, and a detailed biological monitoring plan should be developed to test the hypotheses.

Consideration of potential biological risks will not be easy because the effects of TDG are influenced by variables in the physical environment and the development and behavior of animals of concern. Foremost among these variables is the depth at which the organisms are exposed. Generally, one meter of depth protects aquatic organisms from the effects of 10% TDG via hydrostatic compensation (Weitkamp et al. 2003). For example, if TDG is 120% at the surface, fish at a depth of 2 m will experience 100% TDG. Backman et al. (2002) found that juvenile salmon collected from the forebays (where TDG was 115%) or tailraces (TDG = 120%)

of Columbia River dams had fewer signs of gas bubble disease (GBD) than did fish from the bypass systems of those dams. The authors attributed this disparity to the shallow water in the bypass systems. Steelhead kelts might be particularly affected as the majority passes FCRPS dams through traditional spill routes and spillway weirs (Colotelo et al. 2013). Fish depth behavior may protect them from adverse effects when they come to the surface. That is, time spent at depth protects fish from time spent at the surface (Knittel et al. 1980). This relation between GBD and depth also confounds interpretation of field and laboratory studies because most aquatic organisms are collected in shallow water (Weitkamp 2008) and, in order to control for the effects of hydrostatic compensation, most laboratory studies have been completed in shallow water tanks, for example depths of 0.25m (Mesa et al. 2000; Beeman et al. 2003).

Field studies can offer some insight into potential biological risks associated with high levels of TDG on aquatic organisms, especially fish. Field studies using cages in which fish were able to go to various depths attempt to approximate fish in the wild. Kokanee fry in 9-m deep cages suffered no mortalities even though TDG reached 125% (Weitkamp et al. 2000 cited in Weitkamp 2008, page 10). Schrank et al. (1997, 1998) held juvenile salmonids and several non-salmonid resident fish species in cages with various depths and found that even at TDG as high as 130 to 138%, GBD was low (~6%) in fish held 2 to 3 m deep for four days. Backman et al. (2002) looked at GBD in over 20,000 juvenile salmonids collected from the Snake and Columbia rivers and dams and regressed the incidence of GBD against TDG that varied from 100% to greater than 130%. Their regression suggests that at 125% one would see GBD in fewer than 5% of the fish. Backman and Evans (2002) examined over 8,000 adult steelhead, sockeye, and Chinook salmon below Bonneville Dam when TDG varied between 111% to greater than 130% and found less than 1% with GBD until TDG exceeded 126%. When TDG was between 126% and 130%, incidence of GBD increased in steelhead (~4%) and sockeye (~8%), but in Chinook salmon incidence of GBD stayed < 1%.

Uncontrolled spill at the high-head Libby Dam resulted in TDG between 124% and 131% (Martoz et al. 2007). Signs of GBD in five resident salmonid species and four non-salmonids increased to greater than 90% over the 19 days of spill. However, there were no differences in population estimates or growth of bull trout or *Oncorhynchus* spp. sampled two years before and a year after the high spill (Marotz et al. 2007). Weitkamp (2008) pointed out that, in most studies, signs of GBD are poorly correlated with rate of fish mortality. He points out, however, that historically when TDG has caused significant mortalities in the wild, dead fish were seen. In the Columbia River, a low proportion of fish have been observed with GBD, and it is unlikely that significant mortalities have occurred. However, it is possible that fish condition or health is compromised leading to increased predation.

Studies that have tracked fish depth using radio telemetry showed that juvenile salmonids emigrate at 1.5 to 3.2 m depth (Beeman and Maule 2006), adult salmonids immigrate greater than 2 m deep (Johnson et al. 2005) and a variety of resident fish were found between 2 to 6.8 m deep (Beeman et al. 2003). Thus, it appears that the migratory behavior of juvenile and adult salmonids will help protect them from adverse effects of TDG. There is, however, recent research conducted during uncontrolled spill in 2011, when water below Bonneville Dam had

TDG as high as 134%. The researchers used acoustic telemetry to examine survival of juvenile salmonids in two tests: (1) fish were collected, tagged and transported from Lower Granite Dam then released approximately 10 km below Bonneville Dam into water with TDG at about 115% (low exposure) or about 125% (high exposure); and (2) fish were collected, tagged and released at Bonneville Dam into water with TDG about 118% (low) or about 132% (high). In the Bonneville Dam comparison, daily mortality rate in the lower river was higher in fish when TDG was greater than 130%. In the transported groups, daily mortality rates did not differ in fish as they migrated in the lower river. Daily mortality rates of the high exposure groups were higher than that of the low exposure group in both tests during the fish's migration in the Columbia River plume (Ian Brosnan, Cornell University, personal communication of unpublished data). While these data have not yet been published (they are in review for publication), they suggest that mortality of smolts exposed to TDG greater than 125% may lead to decreased survival beyond the Columbia River, that is, delayed mortality.

Few studies have considered the effects of TDG on amphibians, invertebrate species, or other fish species. Colt et al. (1984, 1987) studied effects of elevated TDG and reported no mortalities in tadpoles (*Rana catesbeiana*) held at about 122% TDG for 4 days. Adult bullfrogs suffered no mortalities at about 117% after 4 days, but 40% died after 1 day at about 132%. Several studies indicated that aquatic invertebrates are much less sensitive to high TDG than are fish (Nebeker et al. 1981; Schrank et al. 1997; Ryan et al. 2000). Ryan et al. (2000) collected over 5,400 invertebrates from the Columbia and Snake rivers at depths less than 0.6 m. They reported finding signs of GBD in only 7 (0.1%) individuals when TDG ranged from 120% to more than 135%. White et al. (1991, as cited in McGrath et al. 2006) found a shift in abundances of some invertebrate species before and after exposure to TDG. However, these effects could have been the result of increased water velocity or changing water temperature (White et al. 1991 as cited in Weitkamp 2008). There is also concern for larval/fry fish in shallow areas with elevated TDG. Studies have shown that bubbles formed in sturgeon larva (Counihan et al. 1998) and sucker fry (Schrank et al. 1998) and interfered with their buoyancy, which could lead to displacement in the habitat or increased vulnerability to predation. While it is assumed that lamprey migrate near the benthos, it is not clear if studies have documented the depth at which lamprey migrate and, thus, the degree to which hydrostatic compensation protects them from GBD.

4. Is the proposed spill experiment likely to add to our existing knowledge regarding spill, juvenile dam passage survival, and adult fish returns (SARs)?

It is likely that a spill test would enhance knowledge about spill, juvenile passage survival, and SARs. A spill test could also increase knowledge in other ways if appropriate monitoring is conducted. The ISAB agrees with the 2013 CSS Workshop conclusion that the experimental design and implementation should "focus on maximizing the amount of learning that can be achieved," where "learning" is the "likelihood of detecting a response." Here again, this situation seems to fit the need for true adaptive management as mentioned above. Alternative covariates and analytical approaches need to be identified and discussed. A preferred alternative action could be identified and applied, and then the models updated periodically, leading to learning that feeds back to management.

Currently, water quality standards and the desire to produce hydropower constrain the amount of water spilled over the dams. CSS annual reports and published papers, however, suggest that increased spill will lead to higher survival of spring Chinook and steelhead. This is a reasonable hypothesis. Nevertheless, as noted under Question 1.A., a detailed and adequately researched hypothesis for the spill experiment is needed, including consideration of alternative hypotheses. Given the potential importance of this study and concerns raised by the Action Agencies and a variety of stakeholders, further vetting of the study design and methodology in a study proposal would be worthwhile as a means to maximize knowledge gained by an experiment. Without a carefully designed experiment that reflects consideration of all possible alternative outcomes, an unexpected result might preclude drawing firm conclusions about the effect of increasing spill.

The ISAB cannot assess whether the ten-year study proposed by CSS is sufficient to detect a meaningful improvement in salmon survival because a detailed proposal has yet to be prepared. However, if adequate monitoring is implemented along with the spill, there should be increased knowledge regarding spill, juvenile salmonid dam passage survival, impacts on adult fish passage and other species, and total dissolved gas effects.

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EXHIBIT C

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September 19, 2018

MEMORANDUM FOR: F/NWR5 – Ritchie Graves

FROM: F/NWC3 - Richard W. Zabel Richard W. Zabel

SUBJECT: Preliminary survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2018

This memorandum summarizes conditions in the Snake and Columbia Rivers and preliminary estimates of survival of PIT-tagged juvenile salmonids passing through reservoirs and dams during the 2018 spring outmigration. We also provide preliminary estimates of the proportion of Snake River smolts that were transported from Snake River dams in 2018. Our complete detailed analyses and report for the spring migration will follow this memo at a later date. As in past years, changes in the database between the time of our annual summer memo and the publication of our final report may result in differences of up to 3 or 4% in estimated survival values.

Summary of Research

For survival studies funded by BPA in 2018, NOAA Fisheries PIT tagged 20,249 river-run hatchery steelhead, 15,396 wild steelhead, and 11,823 wild yearling Chinook salmon for release into the tailrace of Lower Granite Dam.

Survival estimates provided in this memorandum are derived from data from fish PIT tagged by or for NOAA Fisheries, as described above, along with fish PIT tagged by others within the Columbia River Basin. Note that for technical reasons, the statistical model for survival estimation can produce estimates that exceed 100%. When this occurs, we report the actual estimate, but for practical purposes these estimates should be interpreted as representing survival probabilities which are less than or equal to 100%.

We have estimated survival probabilities for migrating PIT-tagged salmonids since 1993. In this memo, we compare 2018 estimates in various river segments to averages over periods of years. Estimates are not available for every reach in every year. Unless otherwise noted, when we refer to a long-term average for a particular river segment, the average is across all years for which estimates are available.

PIT-tagged yearling Chinook salmon have been released from the seven Snake River Basin hatcheries Dworshak, Kooskia, Lookingglass/Imnaha Weir, Rapid River, McCall/Knox Bridge, Pahsimeroi, and Sawtooth every year from 1993 through 2018 (except Pahsimeroi in 1996). Across these “index” hatcheries, the annual mean estimated survival from release to Lower Granite Dam has been relatively stable since 1998 (Figure 1, Table 1). In 2018, the mean was 64.8%; this estimate is close to last year’s mean survival to Lower Granite of 65.0% and the overall mean from 1998 through 2018 of 65.1%. The annual mean has ranged from 49.4% in 1997 to 71.7% in 2016 (Figure 1).

Downstream of Lower Granite Dam, mean estimated survival for Snake River yearling Chinook salmon (hatchery and wild combined) in 2018 was slightly above average in the Lower Granite to Little Goose and the Lower Monumental to McNary reaches, and close to average in the Little Goose to Lower Monumental reach (Table 2, Figure 2). However, estimated survival in the McNary to John Day and John Day to Bonneville reaches was substantially lower than average (Table 2, Figure 3). These estimates resulted in average survival from Lower Granite to McNary, but below average survival in the remaining combined reaches of interest (Table 3).

Mean estimated survival for yearling Chinook salmon from Lower Granite Dam tailrace to McNary Dam tailrace in 2018 was 73.3% (95% CI: 68.4-78.2%). Mean estimated survival from McNary Dam tailrace to Bonneville Dam tailrace was 59.0% (50.2-67.8%). Mean estimated survival for yearling Chinook salmon from Lower Granite Dam tailrace to Bonneville Dam tailrace was 43.2% (36.2-

50.3%). Estimated survival for the Lower Granite project (head of reservoir to tailrace) was 88.0%, based on fish PIT tagged at and released from the Snake River trap. The combined yearling Chinook salmon survival estimate from the Snake River trap to Bonneville Dam tailrace was 38.1% (31.6-44.6%), substantially below the long-term average of 48.9%.

For wild Snake River yearling Chinook, mean estimated survival from Lower Granite Dam tailrace to McNary Dam tailrace was 76.0% (95% CI: 69.9-82.1%), and from McNary Dam tailrace to Bonneville Dam tailrace was 76.2% (48.0-104.4%). Estimated survival from the Snake River trap to Lower Granite Dam tailrace was 87.1%, which resulted in estimated survival from the Snake River trap to Bonneville Dam tailrace of 50.4% (31.0-69.9%). This estimate is above the long-term average of 44.8%.

For Snake River steelhead (hatchery and wild combined), mean estimated survival in 2018 was above average in every individual reach and all resulting combined reaches, though the estimate for the John Day to Bonneville reach was very uncertain (Table 4, Figures 2 and 3). Mean estimated survival for steelhead from Lower Granite Dam tailrace to McNary Dam tailrace was 73.3% (95% CI: 67.2-79.4%). Mean estimated survival from McNary Dam tailrace to Bonneville Dam tailrace was 72.7% (50.8-94.7%). The combined Snake River steelhead survival estimate from the Snake River trap to Bonneville Dam tailrace was 52.4% (35.8-69.0%), which was above the long-term average of 45.6% (Table 5).

For wild Snake River steelhead, mean estimated survival from Lower Granite Dam tailrace to McNary Dam tailrace was 73.6% (95% CI: 58.9-88.3%), and from McNary Dam tailrace to Bonneville Dam tailrace was 82.2% (55.5-108.9%). Estimated survival from the Snake River trap to Lower Granite Dam tailrace was 84.8%, which resulted in estimated survival from the Snake River trap to Bonneville Dam tailrace of 51.3% (30.5-72.1%).

For PIT-tagged hatchery yearling Chinook salmon originating from the upper Columbia River in 2018, estimated survival from McNary Dam tailrace to Bonneville Dam tailrace was 74.9% (95% CI: 60.2-93.2%; Table 6), which was below the long-term average of 81.4%.

For PIT-tagged hatchery steelhead originating from the upper Columbia River in 2018, estimated survival from McNary Dam tailrace to Bonneville Dam tailrace was 116.1% (95% CI: 85.0-158.6%; Table 6). This estimate has high uncertainty; however, unlike Columbia River Chinook, even the low end of the confidence range is above the long-term average of 77.4%.

For fish released from upper Columbia River hatcheries, we cannot estimate survival in reaches upstream from McNary Dam (other than the overall reach from release to McNary Dam tailrace) because of limited PIT-tag detection capabilities at Mid-Columbia River PUD dams.

Estimated survival in 2018 of Snake River sockeye salmon (hatchery and wild combined) from the tailrace of Lower Granite Dam to the tailrace of Bonneville Dam was 64.3% (95% CI: 30.4-50.8%; Table 7). Estimated survival in 2018 of Columbia River sockeye salmon (hatchery and wild combined) from the tailrace of Rock Island Dam to the tailrace of Bonneville Dam was 66.7% (40.7%-61.5%; Table 7). Both estimates were above their respective long-term averages of 40.6% and 51.1%.

Our preliminary estimates of the percentage transported of non-tagged wild and hatchery spring-summer Chinook salmon smolts in 2018 are 44.1% and 45.4%, respectively. For steelhead, the estimates are 47.5% and 46.4% for wild and hatchery smolts, respectively. These estimates represent the percentage of smolts that arrived at Lower Granite Dam that were subsequently transported, either from Lower Granite Dam or downstream at Little Goose or Lower Monumental Dam.

Discussion

For Snake River yearling Chinook salmon in 2018, estimated survival from Lower Granite Dam tailrace to Bonneville Dam tailrace was 43.2%; this estimate is substantially below the long-term (1999-2018) average of 52.1%. Yearling Chinook survival through the hydropower system has been consistently below the mean for the past four years, despite a range of different environmental conditions within these years. These low system survival estimates seem to be driven mostly by poor survival in the McNary to Bonneville reach.

For Snake River steelhead in 2018, estimated survival from Lower Granite Dam tailrace to Bonneville Dam tailrace was 53.3%; above the long-term mean of 47.0% (Table 5). This above-average estimate follows three consecutive years of survival estimates below the mean.

Estimated survival of Snake River sockeye between Lower Granite Dam and Bonneville Dam tailrace was 64.3%, which is the third highest estimate we have in our time series (1998-2018). The component survival estimates for the Lower Granite Dam to McNary Dam reach and the McNary Dam to Bonneville Dam reach were both above average. This above-average estimate follows three consecutive years with very low survival. The Idaho Department of Fish and Game has adjusted their acclimation methods this year in order to address the causes of the low Snake River Sockeye survival from the past three years; their efforts almost certainly contributed to the higher survival estimate this year. Survival of juvenile Upper Columbia River sockeye in the McNary to Bonneville Dam reach was also above average.

Environmental conditions in 2018 resulted in a year with average water temperatures, but high flow and very high spill for most of the migration season. Mean flow at Little Goose Dam in 2018 during the main migration period (1 April–15 June) was 110.8 kcfs, which was well above the long-term (1993-2018) mean of 92.6 kcfs. Daily flow values were above long-term daily means for most of the migration period; daily flow approached the mean for a brief period in early May and fell below the mean after the beginning of June (Figure 4). Mean water temperature at Little Goose Dam in 2018 during the migration period was 11.5 °C, which was near the long-term mean of 11.2 °C. Daily water temperatures generally tracked the long-term daily mean, alternating between slightly above and slightly below the mean through April and May, then remaining slightly above the long-term mean during June (Figure 4).

Mean spill discharge at the Snake River dams during the 2018 migration was 41.3 kcfs, which was substantially above the long-term (1993-2018) mean of 27.7 kcfs. Daily spill discharges remained above the long-term daily mean throughout April and May, with peaks in early May and again near the end of May (Figure 5).

Spill as a percentage of flow at Snake River dams averaged 37.2% in 2018, which was above the long-term (1993-2018) mean of 27.2. Daily mean spill percentages in 2018 were above the long-term daily means for almost the entire migration period (Figure 5), with higher percent spill during early April than in any previous year.

Estimated percentages of yearling Chinook salmon and steelhead transported from Snake River dams in 2018 were substantially higher than in most recent years; 2018 saw one of the highest transportation rates since 2006 (Figure 7). This reversed the recent trend of very low transportation rates seen from 2015-2017.

In 2018, collection of transportation began on 23 April at Lower Granite, Little Goose, and Lower Monumental Dams, which was 8 days earlier than the May 1st start date from most recent years, and the earliest start date for the transportation program since 2006. We estimate that 45% of the annual total passage of wild yearling Chinook and 24% of hatchery yearling Chinook occurred at Lower Granite Dam before transportation began (Figure 6), compared to averages between 2006-2014 of 42% and 31%, respectively. It is worth noting that the percentages passing in 2018 are near average, despite the fact that transportation began earlier in 2018 than in any year in that period except 2006. We estimate that 38% of wild steelhead arrived before transportation began in 2018 (Figure 6), versus the 2006-2014 average of 29%, and 24% of hatchery steelhead versus the average of 33%.

After the beginning of transportation in 2018, higher-than-average proportions of smolts were collected for transportation. This was due to the combination of spill operations and river conditions experienced by the fish as they passed the collector dams. The combination of early transportation start date and relatively higher collection proportions during transportation resulted in the increased percentages of smolts transported in 2018.

Median estimated travel times for both species between Lower Granite Dam and Bonneville Dam in April in 2018 continued the trend from recent years and were substantially shorter than the long-term mean for most of the migration period (1997-2017; Figure 8). These short travel times coincided with the generally high flows and spills in 2018. When flow levels declined at the beginning of June, travel times converged with the mean of recent years.

Since the institution of court-ordered spill in 2006, and the concurrent installation of surface collectors at four additional federal dams during that period, travel times have decreased on average between Lower Granite and Bonneville dams for steelhead, but the effect is less apparent for Chinook (Figure 8). Differences in travel times for low-flow years versus other years are not so well pronounced for either species (Figure 8). Day in season is a stronger predictor of travel time for Chinook than either flow or spill. Some of the lowest flow years were also low-spill years that occurred before the new spill regime, so the effect of average flow on travel time is difficult to separate from that of spill by simply inspecting the figures without the assistance of a statistical model. Flow and spill also vary within season, so categorizing years by seasonal averages is not optimal, but it does allow for some simple visual comparisons.

cc: F/NWC3 – Faulkner
F/NWC3 – Marsh
F/NWC3 – Smith
F/NWC3 – Widener
F/NWC3 – Zabel

Table 1. Estimated survival and standard error (s.e.) for yearling **Chinook** salmon released at Snake River Basin and Upper Columbia River hatcheries to Lower Granite Dam tailrace (LGR) and McNary Dam tailrace (MCN), 2016 through 2018.

	2016		2017		2018[a]	
Hatchery	Survival to LGR (s.e.)	Survival to MCN (s.e.)	Survival to LGR (s.e.)	Survival to MCN (s.e.)	Survival to LGR (s.e.)	Survival to MCN (s.e.)
Dworshak	0.714 (0.007)	0.538 (0.014)	0.693 (0.013)	0.402 (0.015)	0.744 (0.015)	0.546 (0.023)
Kooskia	0.684 (0.012)	0.499 (0.029)	0.565 (0.025)	0.351 (0.040)	0.633 (0.030)	0.438 (0.044)
Lookingglass (Catherine Cr.)	0.371 (0.005)	0.300 (0.016)	0.420 (0.014)	0.303 (0.024)	0.314 (0.008)	0.232 (0.024)
Lookingglass (Grande Ronde)	0.429 (0.016)	0.326 (0.044)	0.398 (0.032)	0.352 (0.096)	0.347 (0.013)	0.238 (0.043)
Lookingglass (Imnaha River)	0.704 (0.007)	0.526 (0.022)	0.585 (0.020)	0.438 (0.041)	0.651 (0.012)	0.429 (0.034)
Lookingglass (Lostine River)	0.586 (0.017)	0.419 (0.039)	0.553 (0.029)	0.409 (0.067)	0.600 (0.014)	0.418 (0.057)
McCall (Johnson Cr.)	---	---	---	---	0.487 (0.029)	0.370 (0.104)
McCall (Knox Bridge)	0.654 (0.006)	0.514 (0.014)	0.700 (0.012)	0.528 (0.021)	0.702 (0.011)	0.519 (0.026)
Pahsimeroi	0.772 (0.008)	0.512 (0.026)	0.746 (0.012)	0.560 (0.041)	0.634 (0.015)	0.342 (0.034)
Rapid River	0.815 (0.005)	0.632 (0.015)	0.652 (0.010)	0.528 (0.020)	0.651 (0.009)	0.491 (0.023)
Sawtooth	0.676 (0.006)	0.474 (0.015)	0.606 (0.010)	0.466 (0.025)	0.519 (0.013)	0.372 (0.029)
Entiat	---	0.631 (0.024)	---	0.639 (0.040)	---	0.572 (0.037)
Winthrop	---	0.577 (0.022)	---	0.578 (0.031)	---	0.587 (0.046)
Leavenworth	---	0.501 (0.016)	---	0.540 (0.022)	---	0.658 (0.038)

a. Estimates are preliminary and subject to change.

Table 2. Annual weighted means of survival probability estimates for yearling **Chinook** salmon (hatchery and wild combined), 1995–2018. Standard errors in parentheses. Reaches with asterisks comprise two dams and reservoirs (i.e., two projects); the following column gives the square root (i.e., geometric mean) of the two–project estimate to facilitate comparison with other single–project estimates. Abbreviations: Trap–Snake River Trap; LGR–Lower Granite Dam; LGO–Little Goose Dam; LMO–Lower Monumental Dam; IHR–Ice Harbor Dam; MCN–McNary Dam; JDA–John Day Dam; TDA–The Dalles Dam; BON–Bonneville Dam. Simple arithmetic means across all available years (1993–2018) are given.

Year	Trap–LGR	LGR–LGO	LGO–LMO	LMO–MCN*	LMO–IHR IHR–MCN	MCN–JDA	JDA–BON*	JDA–TDA TDA–BON
1995	0.905 (0.010)	0.882 (0.004)	0.925 (0.008)	0.876 (0.038)	0.936	NA	NA	NA
1996	0.977 (0.025)	0.926 (0.006)	0.929 (0.011)	0.756 (0.033)	0.870	NA	NA	NA
1997	NA	0.942 (0.018)	0.894 (0.042)	0.798 (0.091)	0.893	NA	NA	NA
1998	0.925 (0.009)	0.991 (0.006)	0.853 (0.009)	0.915 (0.011)	0.957	0.822 (0.033)	NA	NA
1999	0.940 (0.009)	0.949 (0.002)	0.925 (0.004)	0.904 (0.007)	0.951	0.853 (0.027)	0.814 (0.065)	0.902
2000	0.929 (0.014)	0.938 (0.006)	0.887 (0.009)	0.928 (0.016)	0.963	0.898 (0.054)	0.684 (0.128)	0.827
2001	0.954 (0.015)	0.945 (0.004)	0.830 (0.006)	0.708 (0.007)	0.841	0.758 (0.024)	0.645 (0.034)	0.803
2002	0.953 (0.022)	0.949 (0.006)	0.980 (0.008)	0.837 (0.013)	0.915	0.907 (0.014)	0.840 (0.079)	0.917
2003	0.993 (0.023)	0.946 (0.005)	0.916 (0.011)	0.904 (0.017)	0.951	0.893 (0.017)	0.818 (0.036)	0.904
2004	0.893 (0.009)	0.923 (0.004)	0.875 (0.012)	0.818 (0.018)	0.904	0.809 (0.028)	0.735 (0.092)	0.857
2005	0.919 (0.015)	0.919 (0.003)	0.886 (0.006)	0.903 (0.010)	0.950	0.772 (0.029)	1.028 (0.132)	1.014
2006	0.952 (0.011)	0.923 (0.003)	0.934 (0.004)	0.887 (0.008)	0.942	0.881 (0.020)	0.944 (0.030	0.972
2007	0.943 (0.028)	0.938 (0.006)	0.957 (0.010)	0.876 (0.012)	0.936	0.920 (0.016)	0.824 (0.043)	0.908
2008	0.992 (0.018)	0.939 (0.006)	0.950 (0.011)	0.878 (0.016)	0.937	1.073 (0.058)	0.558 (0.082)	0.750
2009	0.958 (0.010)	0.940 (0.006)	0.982 (0.009)	0.855 (0.011)	0.925	0.866 (0.042)	0.821 (0.043)	0.906
2010	0.968 (0.040)	0.962 (0.011)	0.973 (0.019)	0.851 (0.017)	0.922	0.947 (0.021)	0.780 (0.039)	0.883
2011	0.943 (0.009)	0.919 (0.007)	0.966 (0.008)	0.845 (0.012)	0.919	0.893 (0.026)	0.766 (0.080)	0.875
2012	0.928 (0.012)	0.907 (0.009)	0.939 (0.010)	0.937 (0.016)	0.968	0.915 (0.023)	0.866 (0.058)	0.931
2013	0.845 (0.031)	0.922 (0.012)	0.983 (0.014)	0.904 (0.022)	0.951	0.938 (0.058)	0.827 (0.043)	0.909
2014	0.905 (0.015)	0.940 (0.007)	0.919 (0.010)	0.894 (0.017)	0.946	0.912 (0.053)	0.752 (0.104)	0.867
2015	0.909 (0.103)	0.857 (0.036)	0.964 (0.057)	0.802 (0.033)	0.896	0.724 (0.069)	0.937 (0.160)	0.968
2016	0.936 (0.015)	0.956 (0.006)	0.912 (0.100)	0.872 (0.013)	0.934	0.796 (0.039)	0.871 (0.047)	0.933
2017	NA	0.916 (0.009)	0.908 (0.013)	0.912 (0.024)	0.956	0.720 (0.041)	0.871 (0.200)	0.933
2018[a]	0.880 (0.022)	0.942 (0.013)	0.917 (0.019)	0.877 (0.036)	0.936	0.770 (0.074)	0.743 (0.100)	0.862
Mean[b]	**0.930 (0.008)**	**0.928 (0.006)**	**0.922 (0.009)**	**0.863 (0.011)**	**0.929 (0.006)**	**0.860 (0.019)**	**0.806 (0.024)**	**0.896 (0.014)**

a. Estimates are preliminary and subject to change.

b. For each river segment, simple arithmetic mean is across all years for which estimates are available for that segment. Annual estimates for 1993 and 1994 are omitted from the table for space.

Table 3. Hydropower system survival estimates derived by combining empirical survival estimates from various reaches for Snake River yearling **Chinook** salmon (hatchery and wild combined), 1997–2018. Standard errors in parentheses. Abbreviations: Trap–Snake River Trap; LGR–Lower Granite Dam; MCN–McNary Dam; BON–Bonneville Dam.

Year	Trap–LGR	LGR-MCN	MCN-BON	LGR–BON	Trap–BON
1997	NA	0.653 (0.072)	NA	NA	NA
1998	0.924 (0.011)	0.770 (0.009)	NA	NA	NA
1999	0.940 (0.009)	0.792 (0.006)	0.704 (0.058)	0.557 (0.046)	0.524 (0.043)
2000	0.929 (0.014)	0.760 (0.012)	0.640 (0.122)	0.486 (0.093)	0.452 (0.087)
2001	0.954 (0.015)	0.556 (0.009)	0.501 (0.027)	0.279 (0.016)	0.266 (0.016)
2002	0.953 (0.022)	0.757 (0.009)	0.763 (0.079)	0.578 (0.060)	0.551 (0.059)
2003	0.993 (0.023)	0.731 (0.010)	0.728 (0.030)	0.532 (0.023)	0.528 (0.026)
2004	0.893 (0.009)	0.666 (0.011)	0.594 (0.074)	0.395 (0.050)	0.353 (0.045)
2005	0.919 (0.015)	0.732 (0.009)	0.788 (0.093)	0.577 (0.068)	0.530 (0.063)
2006	0.952 (0.011)	0.764 (0.007)	0.842 (0.021)	0.643 (0.017)	0.612 (0.018)
2007	0.943 (0.028)	0.783 (0.006)	0.763 (0.044)	0.597 (0.035)	0.563 (0.037)
2008	0.992 (0.018)	0.782 (0.011)	0.594 (0.066)	0.465 (0.052)	0.460 (0.052)
2009	0.958 (0.010)	0.787 (0.007)	0.705 (0.031)	0.555 (0.025)	0.531 (0.025)
2010	0.968 (0.040)	0.772 (0.012)	0.738 (0.039)	0.569 (0.032)	0.551 (0.038)
2011	0.943 (0.009)	0.746 (0.010)	0.687 (0.065)	0.513 (0.049)	0.483 (0.046)
2012	0.928 (0.012)	0.790 (0.016)	0.802 (0.051)	0.634 (0.042)	0.588 (0.040)
2013	0.845 (0.031)	0.781 (0.016)	0.792 (0.071)	0.622 (0.052)	0.525 (0.048)
2014	0.905 (0.015)	0.768 (0.015)	0.715 (0.107)	0.549 (0.083)	0.497 (0.075)
2015	0.909 (0.103)	0.680 (0.035)	0.629 (0.043)	0.428 (0.037)	0.389 (0.055)
2016	0.936 (0.015)	0.752 (0.011)	0.672 (0.060)	0.505 (0.046)	0.473 (0.043)
2017	NA	0.743 (0.019)	0.643 (0.157)	0.478 (0.117)	NA
2018[a]	0.880 (0.022)	0.733 (0.025)	0.590 (0.045)	0.432 (0.036)	0.381 (0.033)
Mean[b]	**0.930 (0.008)**	**0.738 (0.012)**	**0.695 (0.019)**	**0.521 (0.020)**	**0.489 (0.020)**

a. Estimates are preliminary and subject to change.

b. For each river segment, simple arithmetic mean is across all years for which estimates are available for that segment. Annual estimates for 1993-1996 are omitted from the table for space.

Table 4. Annual weighted means of survival probability estimates for **steelhead** (hatchery and wild combined), 1995–2018. Standard errors in parentheses. Reaches with asterisks comprise two dams and reservoirs (i.e., two projects); the following column gives the square root (i.e., geometric mean) of the two–project estimate to facilitate comparison with other single–project estimates. Abbreviations: Trap–Snake River Trap; LGR–Lower Granite Dam; LGO–Little Goose Dam; LMO–Lower Monumental Dam; IHR–Ice Harbor Dam; MCN–McNary Dam; JDA–John Day Dam; TDA–The Dalles Dam; BON–Bonneville Dam. Simple arithmetic means across all available years (1993–2018) are given.

Year	Trap–LGR	LGR–LGO	LGO–LMO	LMO–MCN*	LMO–IHR IHR–MCN	MCN–JDA	JDA–BON*	JDA–TDA TDA–BON
1995	0.945 (0.008)	0.899 (0.005)	0.962 (0.011)	0.858 (0.076)	0.926	NA	NA	NA
1996	0.951 (0.015)	0.938 (0.008)	0.951 (0.014)	0.791 (0.052)	0.889	NA	NA	NA
1997	0.964 (0.015)	0.966 (0.006)	0.902 (0.020)	0.834 (0.065)	0.913	NA	NA	NA
1998	0.924 (0.009)	0.930 (0.004)	0.889 (0.006)	0.797 (0.018)	0.893	0.831 (0.031)	0.935 (0.103)	0.967
1999	0.908 (0.011)	0.926 (0.004)	0.915 (0.006)	0.833 (0.011)	0.913	0.920 (0.033)	0.682 (0.039)	0.826
2000	0.964 (0.013)	0.901 (0.006)	0.904 (0.009)	0.842 (0.016)	0.918	0.851 (0.045)	0.754 (0.045)	0.868
2001	0.911 (0.007)	0.801 (0.010)	0.709 (0.008)	0.296 (0.010)	0.544	0.337 (0.025)	0.753 (0.063)	0.868
2002	0.895 (0.015)	0.882 (0.011)	0.882 (0.018)	0.652 (0.031)	0.807	0.844 (0.063)	0.612 (0.098)	0.782
2003	0.932 (0.015)	0.947 (0.005)	0.898 (0.012)	0.708 (0.018)	0.841	0.879 (0.032)	0.630 (0.066)	0.794
2004	0.948 (0.004)	0.860 (0.006)	0.820 (0.014)	0.519 (0.035)	0.720	0.465 (0.078)	NA	NA
2005	0.967 (0.004)	0.940 (0.004)	0.867 (0.009)	0.722 (0.023)	0.850	0.595 (0.040)	NA	NA
2006	0.920 (0.013)	0.956 (0.004)	0.911 (0.006)	0.808 (0.017)	0.899	0.795 (0.045)	0.813 (0.083)	0.902
2007	1.016 (0.026)	0.887 (0.009)	0.911 (0.022)	0.852 (0.030)	0.923	0.988 (0.098)	0.579 (0.059)	0.761
2008	0.995 (0.018)	0.935 (0.007)	0.961 (0.014)	0.776 (0.017)	0.881	0.950 (0.066)	0.742 (0.045)	0.861
2009	1.002 (0.011)	0.972 (0.005)	0.942 (0.008)	0.863 (0.014)	0.929	0.951 (0.026)	0.900 (0.079)	0.949
2010	1.017 (0.030)	0.965 (0.028)	0.984 (0.044)	0.876 (0.032)	0.936	0.931 (0.051)	0.840 (0.038)	0.917
2011	0.986 (0.017)	0.955 (0.004)	0.948 (0.010)	0.772 (0.014)	0.879	0.960 (0.043)	0.858 (0.051)	0.926
2012	1.001 (0.026)	0.959 (0.006)	0.914 (0.011)	0.811 (0.022)	0.901	0.814 (0.048)	1.021 (0.148)	1.010
2013	0.973 (0.032)	0.921 (0.020)	0.977 (0.020)	0.739 (0.031)	0.860	0.799 (0.025)	1.026 (0.154)	1.013
2014	1.018 (0.028)	0.953 (0.009)	0.947 (0.024)	0.836 (0.032)	0.914	1.082 (0.080)	0.982 (0.147)	0.991
2015	0.874 (0.046)	0.848 (0.039)	0.834 (0.060)	0.939 (0.073)	0.969	0.792 (0.066)	0.842 (0.050)	0.918
2016	0.998 (0.016)	0.990 (0.007)	0.918 (0.016)	0.813 (0.025)	0.902	0.927 (0.074)	0.709 (0.071)	0.842
2017	NA	0.962 (0.008)	0.943 (0.015)	0.849 (0.022)	0.921	0.941 (0.020)	0.643 (0.040)	0.802
2018[a]	0.983 (0.025)	0.953 (0.007)	0.950 (0.016)	0.823 (0.036)	0.907	0.847 (0.068)	0.949 (0.137)	0.974
Mean[b]	**0.952 (0.011)**	**0.930 (0.010)**	**0.909 (0.012)**	**0.775 (0.027)**	**0.876 (0.018)**	**0.833 (0.038)**	**0.804 (0.032)**	**0.893 (0.018)**

a. Estimates are preliminary and subject to change.

b. For each river segment, simple arithmetic mean is across all years for which estimates are available for that segment. Annual estimates for 1993 and 1994 are omitted from the table for space.

Table 5. Hydropower system survival estimates derived by combining empirical survival estimates from various reaches for Snake River **steelhead** (hatchery and wild combined), 1997–2018. Standard errors in parentheses. Abbreviations: Trap–Snake River Trap; LGR–Lower Granite Dam; MCN–McNary Dam; BON–Bonneville Dam.

Year	Trap–LGR	LGR-MCN	MCN-BON	LGR–BON	Trap–BON
1997	0.964 (0.015)	0.728 (0.053)	0.651 (0.082)	0.474 (0.069)	0.457 (0.067)
1998	0.924 (0.009)	0.649 (0.013)	0.770 (0.081)	0.500 (0.054)	0.462 (0.050)
1999	0.908 (0.011)	0.688 (0.010)	0.640 (0.024)	0.440 (0.018)	0.400 (0.017)
2000	0.964 (0.013)	0.679 (0.016)	0.580 (0.040)	0.393 (0.034)	0.379 (0.033)
2001	0.911 (0.007)	0.168 (0.006)	0.250 (0.016)	0.042 (0.003)	0.038 (0.003)
2002	0.895 (0.015)	0.536 (0.025)	0.488 (0.090)	0.262 (0.050)	0.234 (0.045)
2003	0.932 (0.015)	0.597 (0.013)	0.518 (0.015)	0.309 (0.011)	0.288 (0.012)
2004	0.948 (0.004)	0.379 (0.023)	NA	NA	NA
2005	0.967 (0.004)	0.593 (0.018)	NA	NA	NA
2006	0.920 (0.013)	0.702 (0.016)	0.648 (0.079)	0.455 (0.056)	0.418 (0.052)
2007	1.016 (0.026)	0.694 (0.020)	0.524 (0.064)	0.364 (0.045)	0.369 (0.047)
2008	0.995 (0.018)	0.716 (0.015)	0.671 (0.034)	0.480 (0.027)	0.478 (0.028)
2009	1.002 (0.011)	0.790 (0.013)	0.856 (0.074)	0.676 (0.059)	0.678 (0.060)
2010	1.017 (0.030)	0.770 (0.020)	0.789 (0.027)	0.608 (0.026)	0.618 (0.032)
2011	0.986 (0.017)	0.693 (0.013)	0.866 (0.038)	0.600 (0.029)	0.592 (0.030)
2012	1.001 (0.026)	0.698 (0.020)	0.856 (0.196)	0.597 (0.138)	0.598 (0.139)
2013	0.973 (0.032)	0.645 (0.026)	0.798 (0.112)	0.515 (0.075)	0.501 (0.075)
2014	1.018 (0.028)	0.740 (0.021)	1.023 (0.088)	0.757 (0.069)	0.771 (0.073)
2015	0.874 (0.046)	0.628 (0.033)	0.663 (0.039)	0.416 (0.033)	0.364 (0.034)
2016	0.998 (0.016)	0.730 (0.020)	0.608 (0.040)	0.444 (0.032)	0.443 (0.032)
2017	NA	0.759 (0.019)	0.605 (0.037)	0.459 (0.030)	NA
2018[a]	0.983 (0.025)	0.733 (0.031)	0.727 (0.112)	0.533 (0.085)	0.524 (0.085)
Mean[b]	**0.952 (0.011)**	**0.660 (0.028)**	**0.677 (0.038)**	**0.470 (0.035)**	**0.456 (0.038)**

a. Estimates are preliminary and subject to change.

b. For each river segment, simple arithmetic mean is across all years for which estimates are available for that segment. Annual estimates for 1993-1996 are omitted for space.

Table 6. Estimated survival and standard error (s.e.) through reaches of the lower Columbia River hydropower system for hatchery yearling **Chinook** salmon and **steelhead** originating in the upper Columbia River, 1999–2018. Abbreviations: Rel–Release site; MCN–McNary Dam; JDA–John Day Dam; BON–Bonneville Dam.

	Yearling Chinook Salmon				Steelhead			
Year	Rel–MCN	MCN-JDA	JDA-BON	MCN–BON	Rel–MCN	MCN-JDA	JDA-BON	MCN–BON
1999	0.572 (0.014)	0.896 (0.044)	0.795 (0.129)	0.712 (0.113)	NA	NA	NA	NA
2000	0.539 (0.025)	0.781 (0.094)	NA	NA	NA	NA	NA	NA
2001	0.428 (0.009)	0.881 (0.062)	NA	NA	NA	NA	NA	NA
2002	0.555 (0.003)	0.870 (0.011)	0.940 (0.048)	0.817 (0.041)	NA	NA	NA	NA
2003	0.625 (0.003)	0.900 (0.008)	0.977 (0.035)	0.879 (0.031)	0.471 (0.004)	0.997 (0.012)	0.874 (0.036)	0.871 (0.036)
2004	0.507 (0.005)	0.812 (0.019)	0.761 (0.049)	0.618 (0.038)	0.384 (0.005)	0.794 (0.021)	1.037 (0.112)	0.823 (0.088)
2005	0.545 (0.012)	0.751 (0.042)	NA	NA	0.399 (0.004)	0.815 (0.017)	0.827 (0.071)	0.674 (0.057)
2006	0.520 (0.011)	0.954 (0.051)	0.914 (0.211)	0.871 (0.198)	0.397 (0.008)	0.797 (0.026)	0.920 (0.169)	0.733 (0.134)
2007	0.584 (0.009)	0.895 (0.028)	0.816 (0.091)	0.730 (0.080)	0.426 (0.016)	0.944 (0.064)	0.622 (0.068)	0.587 (0.059)
2008	0.582 (0.019)	1.200 (0.085)	0.522 (0.114)	0.626 (0.133)	0.438 (0.015)	NA	NA	NA
2009	0.523 (0.013)	0.847 (0.044)	1.056 (0.143)	0.895 (0.116)	0.484 (0.018)	0.809 (0.048)	0.935 (0.133)	0.756 (0.105)
2010	0.660 (0.014)	0.924 (0.040)	0.796 (0.046)	0.735 (0.037)	0.512 (0.017)	0.996 (0.054)	0.628 (0.038)	0.626 (0.033)
2011	0.534 (0.010)	1.042 (0.047)	0.612 (0.077)	0.637 (0.077)	0.435 (0.012)	1.201 (0.064)	0.542 (0.101)	0.651 (0.119)
2012	0.576 (0.012)	0.836 (0.035)	1.140 (0.142)	0.953 (0.115)	0.281 (0.011)	0.862 (0.047)	1.240 (0.186)	1.069 (0.159)
2013	0.555 (0.013)	0.965 (0.050)	1.095 (0.129)	1.056 (0.117)	0.384 (0.020)	0.957 (0.071)	0.974 (0.104)	0.932 (0.099)
2014	0.571 (0.013)	0.974 (0.047)	0.958 (0.122)	0.933 (0.114)	0.468 (0.043)	0.883 (0.124)	0.807 (0.153)	0.712 (0.130)
2015	0.512 (0.015)	0.843 (0.043)	1.032 (0.081)	0.870 (0.062)	0.351 (0.019)	0.807 (0.084)	0.707 (0.073)	0.570 (0.043)
2016	0.610 (0.009)	0.857 (0.027)	0.942 (0.068)	0.807 (0.055)	0.416 (0.011)	0.771 (0.037)	0.633 (0.046)	0.487 (0.032)
2017	0.582 (0.013)	0.853 (0.030)	1.107 (0.142)	0.944 (0.120)	0.437 (0.025)	0.880 (0.062)	1.095 (0.210)	0.964 (0.188)
2018[a]	0.608 (0.016)	0.914 (0.044)	0.820 (0.096)	0.749 (0.084)	0.416 (0.021)	0.942 (0.062)	1.232 (0.194)	1.161 (0.186)
Mean[b]	**0.559 (0.012)**	**0.900 (0.022)**	**0.899 (0.042)**	**0.814 (0.031)**	**0.419 (0.014)**	**0.897 (0.029)**	**0.872 (0.057)**	**0.774 (0.050)**

a. Estimates are preliminary and subject to change.

b. For each river segment, simple arithmetic mean is across all years for which estimates are available for that segment.

Table 7. Estimated survival and standard error (s.e.) for **sockeye** salmon (hatchery and wild combined) from Lower Granite Dam tailrace to Bonneville Dam tailrace for fish originating in the Snake River, and from Rock Island Dam tailrace to Bonneville Dam tailrace for fish originating in the upper Columbia River, 1996–2018. Note that this table represents all available data on sockeye; estimates are provided regardless of the precision, which in some years was very poor. Abbreviations: LGR–Lower Granite Dam; MCN–McNary Dam; BON–Bonneville Dam; RIS–Rock Island Dam.

	Snake River Sockeye			Upper Columbia River Sockeye		
Year	LGR-MCN	MCN-BON	LGR-BON	RIS-MCN	MCN-BON	RIS-BON
1996	0.283 (0.184)	NA	NA	NA	NA	NA
1997	NA	NA	NA	0.397 (0.119)	NA	NA
1998	0.689 (0.157)	0.142 (0.099)	0.177 (0.090)	0.624 (0.058)	1.655 (1.617)	1.033 (1.003)
1999	0.655 (0.083)	0.841 (0.584)	0.548 (0.363)	0.559 (0.029)	0.683 (0.177)	0.382 (0.097)
2000	0.679 (0.110)	0.206 (0.110)	0.161 (0.080)	0.487 (0.114)	0.894 (0.867)	0.435 (0.410)
2001	0.205 (0.063)	0.105 (0.050)	0.022 (0.005)	0.657 (0.117)	NA	NA
2002	0.524 (0.062)	0.684 (0.432)	0.342 (0.212)	0.531 (0.044)	0.286 (0.110)	0.152 (0.057)
2003	0.669 (0.054)	0.551 (0.144)	0.405 (0.098)	NA	NA	NA
2004	0.741 (0.254)	NA	NA	0.648 (0.114)	1.246 (1.218)	0.808 (0.777)
2005	0.388 (0.078)	NA	NA	0.720 (0.140)	0.226 (0.209)	0.163 (0.147)
2006	0.630 (0.083)	1.113 (0.652)	0.820 (0.454)	0.793 (0.062)	0.767 (0.243)	0.608 (0.187)
2007	0.679 (0.066)	0.259 (0.084)	0.272 (0.073)	0.625 (0.046)	0.642 (0.296)	0.401 (0.183)
2008	0.763 (0.103)	0.544 (0.262)	0.404 (0.179)	0.644 (0.094)	0.679 (0.363)	0.437 (0.225)
2009	0.749 (0.032)	0.765 (0.101)	0.573 (0.073)	0.853 (0.076)	0.958 (0.405)	0.817 (0.338)
2010	0.723 (0.039)	0.752 (0.098)	0.544 (0.077)	0.778 (0.063)	0.627 (0.152)	0.488 (0.111)
2011	0.659 (0.033)	NA	NA	0.742 (0.088)	0.691 (0.676)	0.513 (0.498)
2012	0.762 (0.032)	0.619 (0.084)	0.472 (0.062)	0.945 (0.085)	0.840 (0.405)	0.794 (0.376)
2013	0.691 (0.043)	0.776 (0.106)	0.536 (0.066)	0.741 (0.068)	0.658 (0.217)	0.487 (0.155)
2014	0.873 (0.054)	0.817 (0.115)	0.713 (0.096)	0.428 (0.056)	0.565 (0.269)	0.242 (0.111)
2015	0.702 (0.054)	0.531 (0.151)	0.373 (0.037)	0.763 (0.182)	0.446 (0.200)	0.340 (0.130)
2016	0.523 (0.047)	0.227 (0.059)	0.119 (0.030)	0.807 (0.082)	0.545 (0.126)	0.448 (0.144)
2017	0.544 (0.081)	0.324 (0.107)	0.176 (0.055)	0.719 (0.113)	0.611 (0.181)	0.500 (0.332)
2018[a]	0.684 (0.061)	0.940 (0.151)	0.643 (0.088)	0.560 (0.112)	0.839 (0.095)	0.667 (0.144)
Mean[b]	**0.628 (0.034)**	**0.566 (0.070)**	**0.406 (0.052)**	**0.668 (0.031)**	**0.729 (0.074)**	**0.511 (0.053)**

a. Estimates are preliminary and subject to change.

b. For each river segment, simple arithmetic mean is across all years for which estimates are available for that segment.

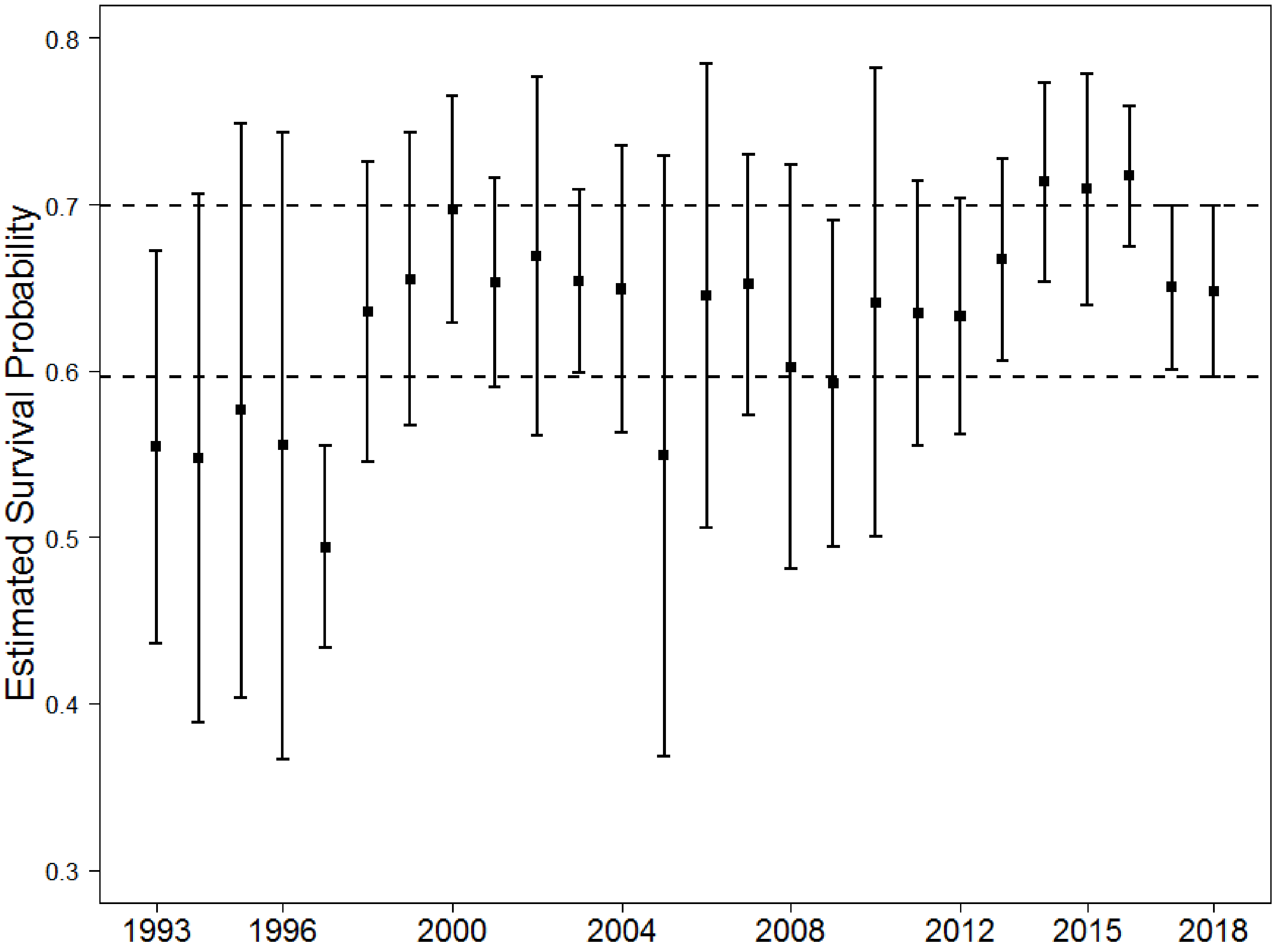


Figure 1. Annual average survival estimates from release to Lower Granite Dam for PIT-tagged yearling **Chinook** salmon released from Snake River Basin hatcheries, 1993-2018. Hatcheries used for average (index groups) are those with consistent PIT-tag releases through the series of years shown. Vertical bars represent 95% confidence intervals. Horizontal dashed lines are the 2018 confidence interval endpoints and are shown for comparison to other years.

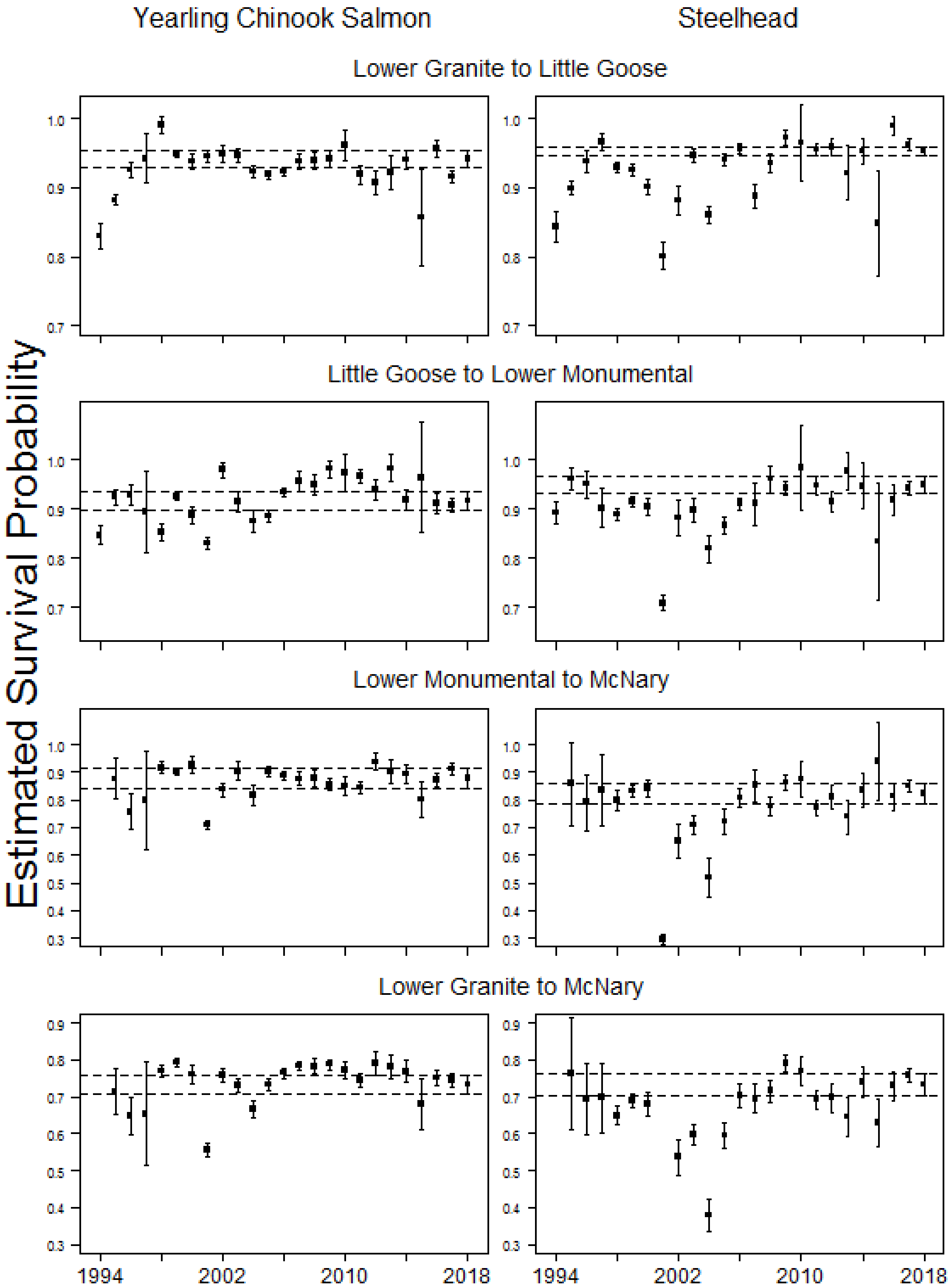


Figure 2. Annual average survival estimates for PIT-tagged yearling **Chinook** salmon and **steelhead**, hatchery and wild fish combined. Vertical bars represent 95% confidence intervals. Horizontal dashed lines are 95% confidence interval endpoints for 2018 estimates.

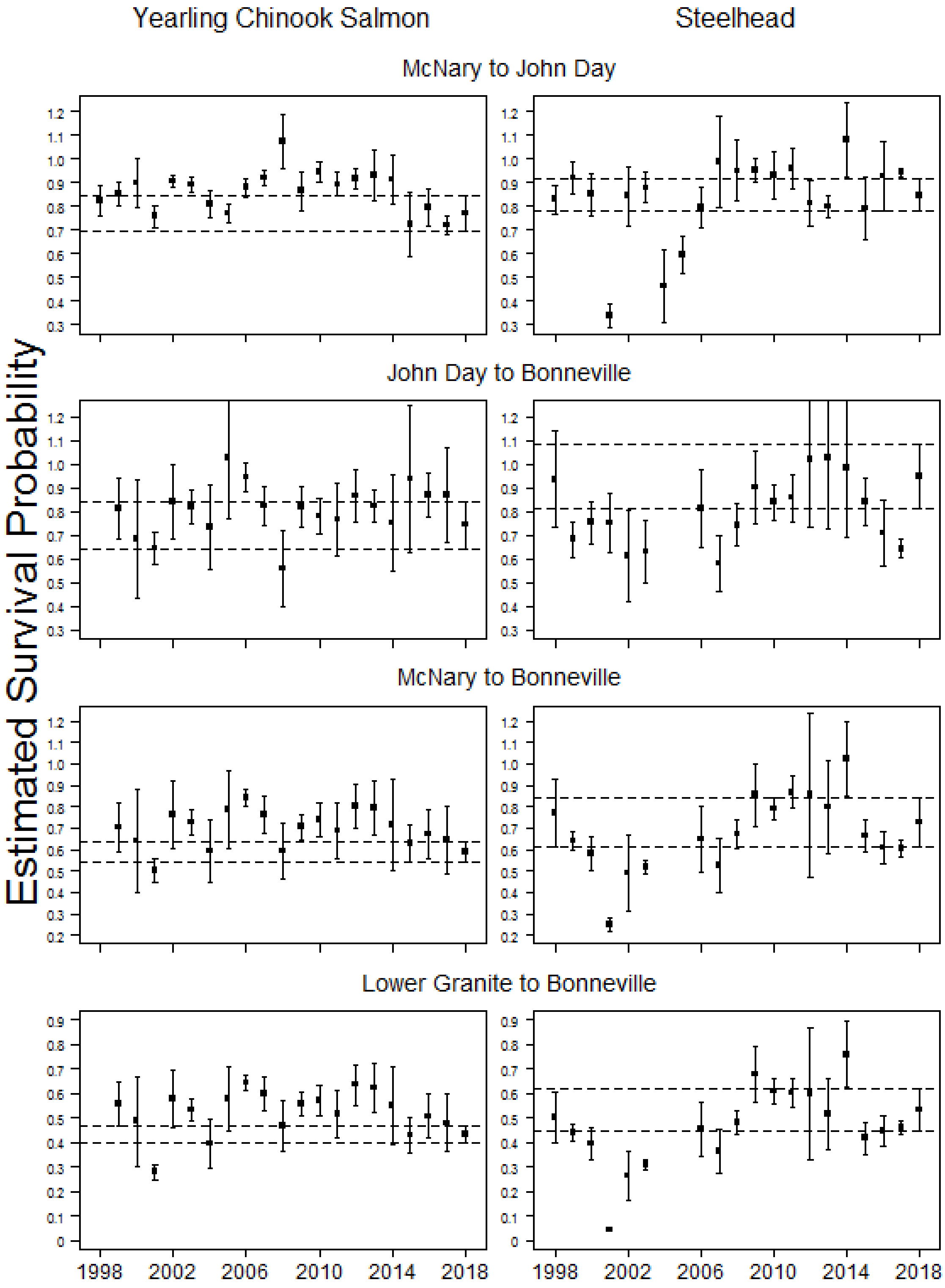
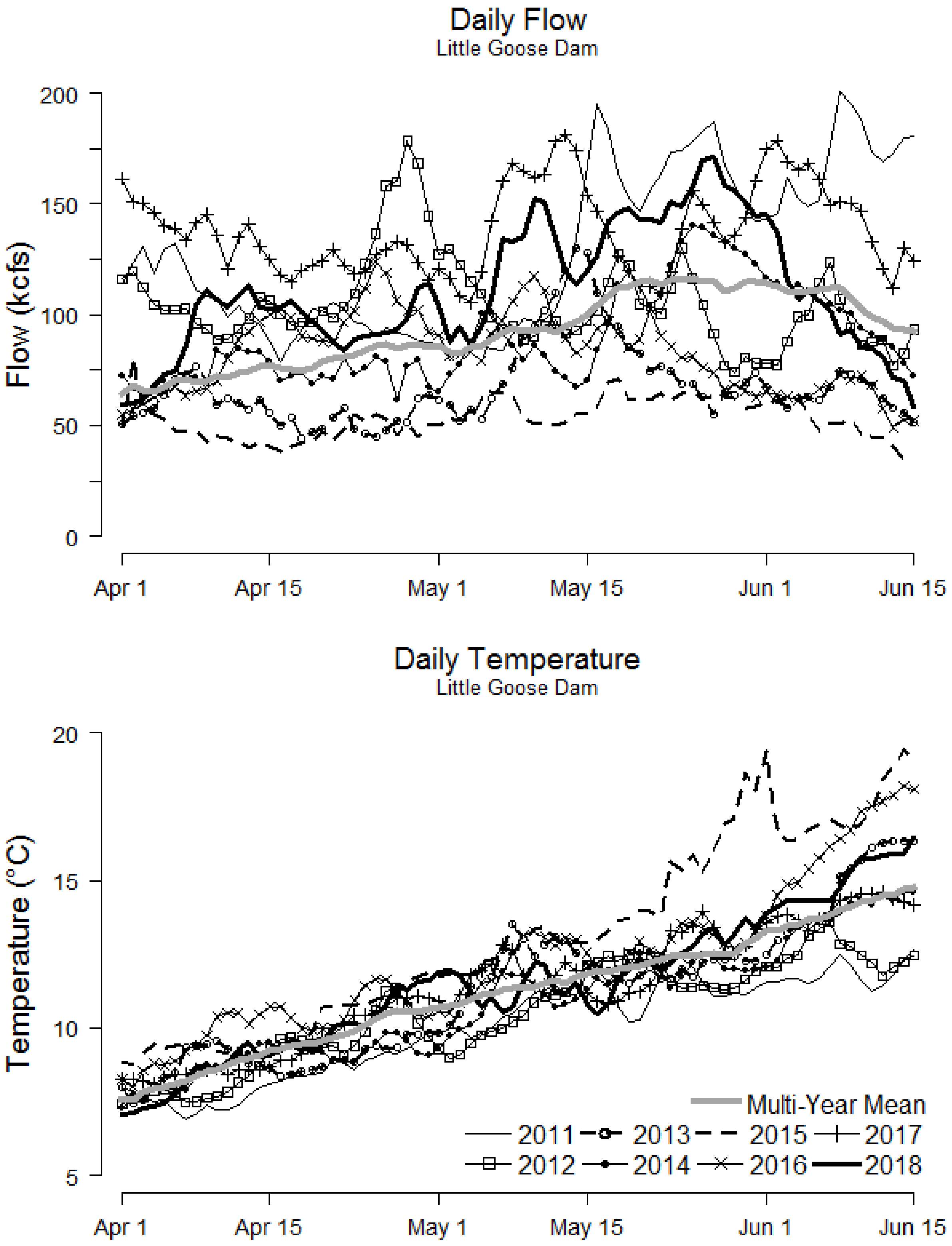


Figure 3. Annual average survival estimates for PIT-tagged yearling **Chinook** salmon and **steelhead**, hatchery and wild fish combined. Vertical bars represent 95% confidence intervals. Horizontal dashed lines are 95% confidence interval endpoints for 2018 estimates.


Daily Flow
Little Goose Dam

Daily Temperature
Little Goose Dam

Figure 4. Snake River flow (kcfs; top panel) and water temperature (°C; bottom panel) measured at Little Goose Dam during April and May, 2011-2018, including daily long-term means (1993-2018).

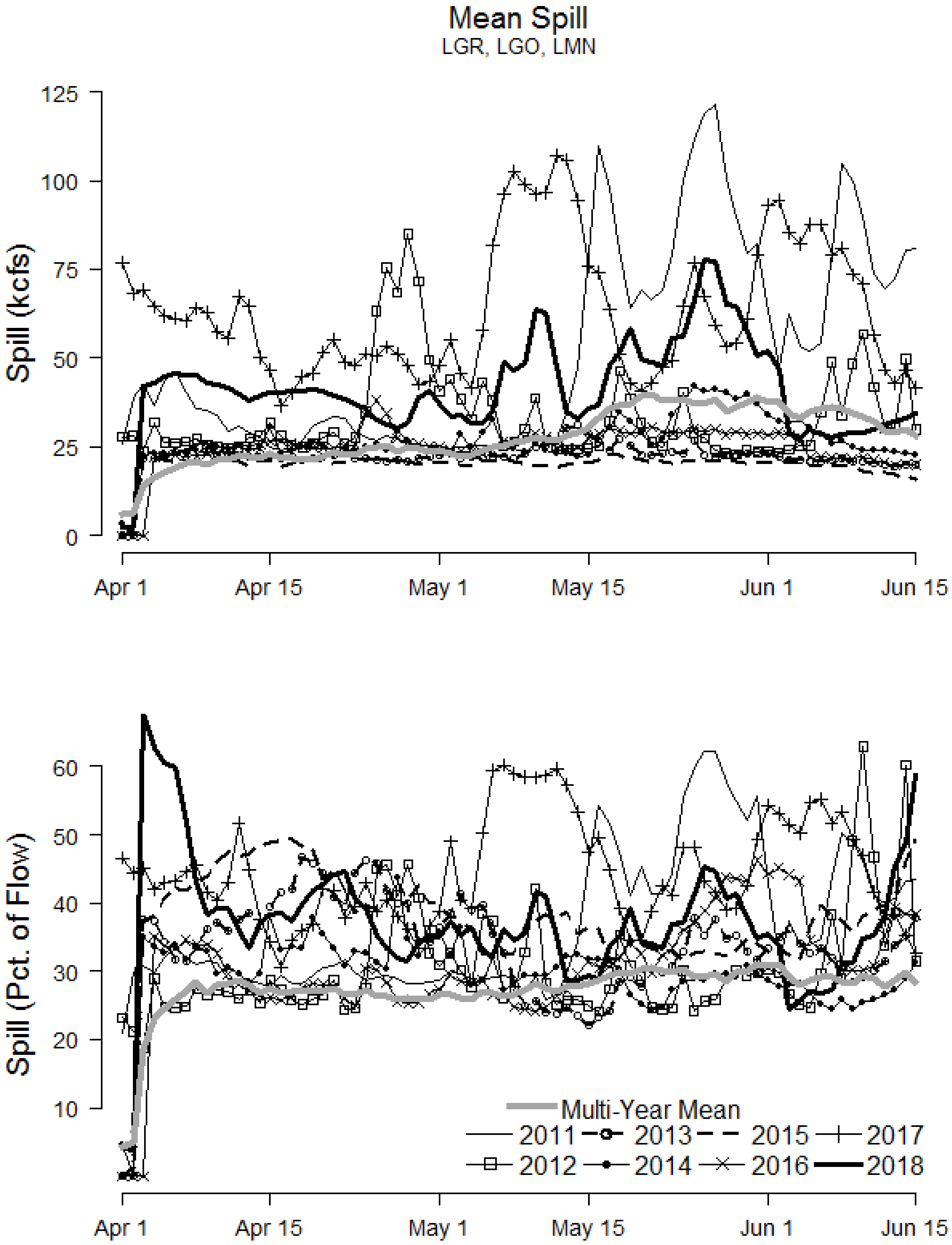


Figure 5. Mean spill (top panel shows kcfs; bottom panel shows percentage of total flow) at Snake River dams during April and May, 2011-2018, including daily long-term means (1993-2018).

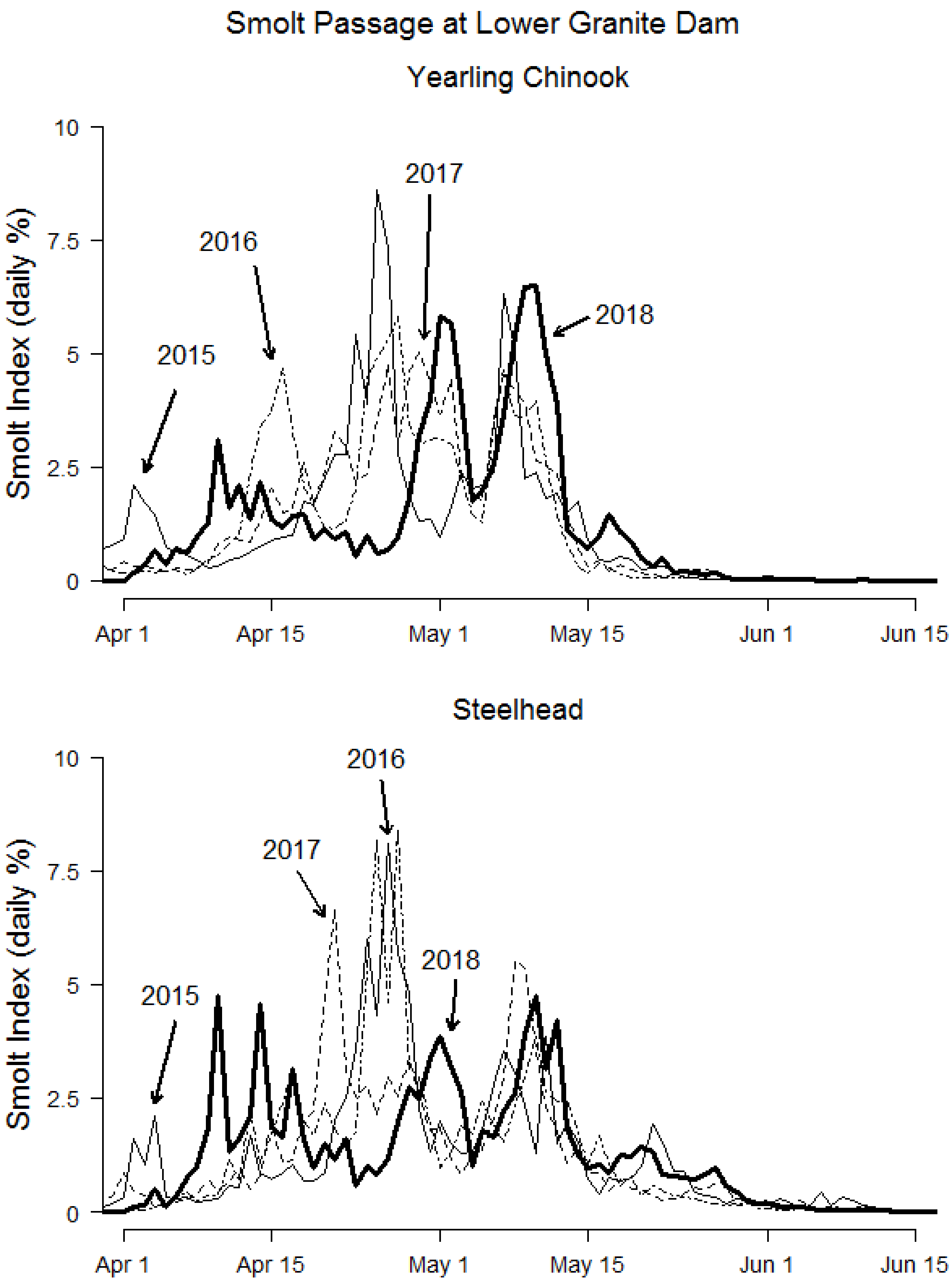


Figure 6. Smolt index as daily percentage of total passage at Lower Granite Dam 2015-2018 for hatchery and wild combined yearling **Chinook** and **steelhead**.

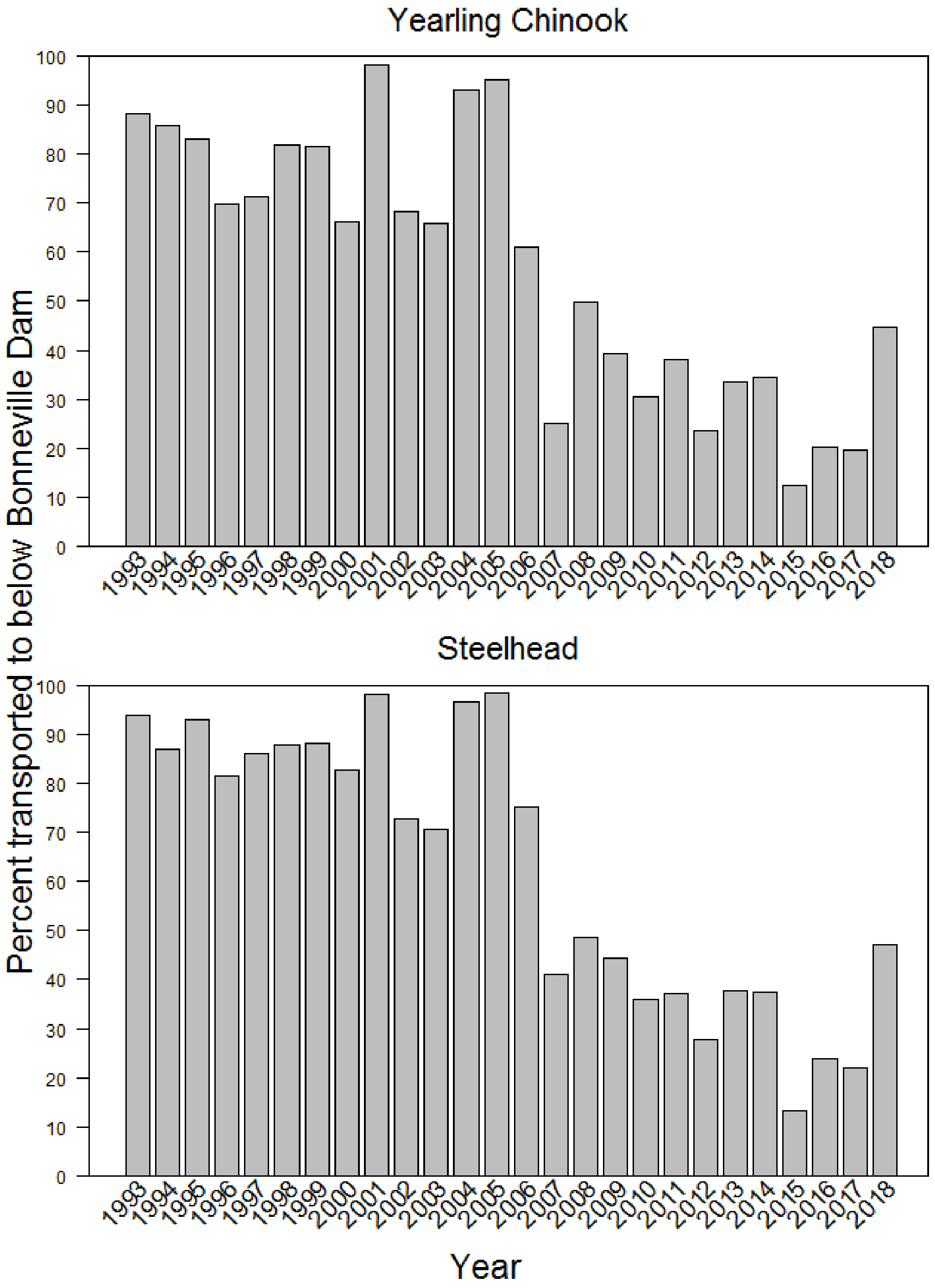


Figure 7. Estimated percent of yearling **Chinook** salmon and **steelhead** (hatchery and wild combined) transported to below Bonneville Dam by year (1993-2018).

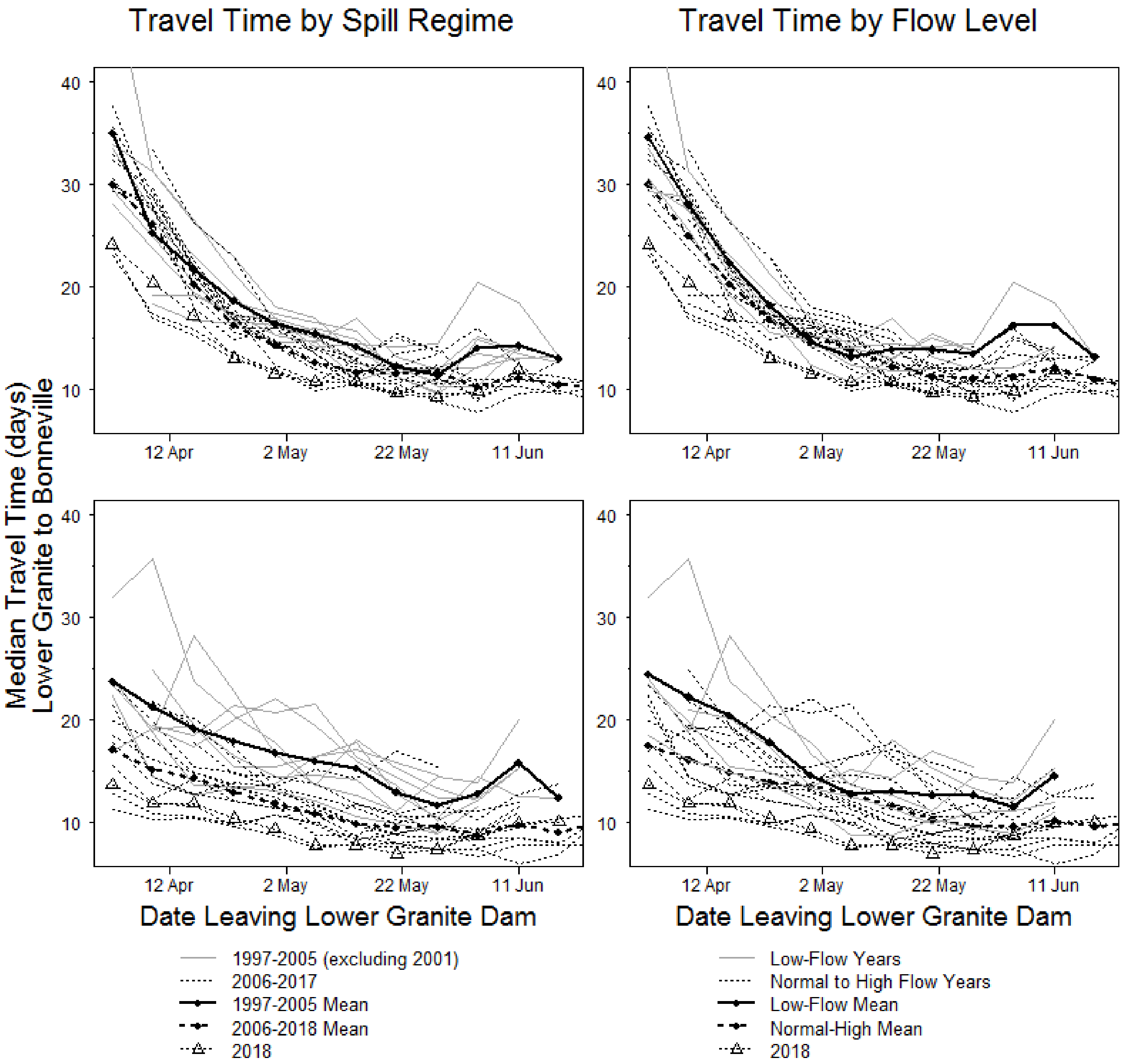


Figure 8. Median travel time from Lower Granite Dam to Bonneville Dam for yearling **Chinook** salmon and **steelhead** by spill regime (left) and mean flow category (right) in the period 1998-2018 (excluding 2001), with long-term mean for the same period. Here spill regime is defined by court-ordered spill starting in 2006 and the concurrent installation of additional surface collectors, and low-flow years are those with mean of 70 kcfs or less for the period of 1 April through 15 June. The 2001 migration year is excluded from the individual years and means due to its unusual combination of low flow and no spill and the influence that has on the group means.